Human Health Risk Assessment
377 Winona Avenue and
381 Winona Avenue, Ottawa, Ontario

Submitted to: **Paterson Group**
154 Colonnade Road South
Ottawa, Ontario

Submitted by: **NovaTox Inc.**
10 Crane Avenue, Unit B
Guelph, Ontario

August 2022
NovaTox Project 20-541

NovaTox Inc.
10 Crane Avenue, Guelph, Ontario N1G 2R2
Tel 1.877.680.7256 • Fax 1.519.231.0130 • http://novatox.ca

Contents

Tables

Appendix

1. Introduction

NovaTox Inc. (NovaTox) was retained by Paterson Group Inc. (Paterson) on behalf of the property owner to conduct a human health risk assessment (HHRA) for the buildings located at 377 Winona Avenue and 381 Winona Avenue in Ottawa, Ontario. The RA was completed for non-regulatory, or due-diligence, purposes. It is understood that this report will not be submitted for review and approval by the Ontario Ministry of Environment, Conservation and Parks (MECP) or used to support a Record of Site Condition (RSC) under Ontario's brownfield regulation (O. Reg. 153/04, as amended).

The primary focus of the HHRA is with regard to human health risks due to the inhalation of vapours that may migrate from subsurface groundwater impacts (i.e., vapours sourced from groundwater) into the existing on-site buildings.

Information and data that form the basis of this report were obtained from the following report that was made available to NovaTox:

1. Paterson (2021). Phase II Environmental Site Assessment: 377 and 381 Winona Avenue, Ottawa, Ontario. Prepared for 10731854 Canada Inc. Prepared by Paterson Group Inc. Report PE5222-2. Dated October 15, 2021.

The reader is referred to the above report for full details on its methodology and results, including additional details and drawings illustrating the study area, potential environmental concerns, contaminants, geological and hydrogeological interpretations, and extent of contamination.

A brief summary of aspects particularly relevant to the development of the HHRA is provided in the remainder of Section 1. All details of the methods and results of the HHRA are provided in Section 2. A concluding summary of risks and recommendations is provided in Section 3.

1.1. Site Description

The site is is located on the east side of Winona Avenue, in the southeast quadrant of the Picton Avenue and Winona Avenue intersection, in the City of Ottawa, Ontario. The site is in an area of the city that has a mixture of commercial and residential properties. The Paterson ESA report shows the general location of the site.

The site is rectangular with an approximate area of 938 m^2. The site is occupied by two residential dwellings, with the municipal addresses 377 Winona Avenue (a 2-storey building with dimensions of approximately 15 m by 10 m) and 381 Winona Avenue (a 3-storey building with dimensions of approximately 21 m by 9 m). The site is to be redeveloped for residential purposes (i.e., no change in land use).

1.2. Site Investigations

Paterson identified a total of 22 potentially contaminating activities (PCAs) at the site and surrounding area (i.e., the Phase I study area), and in turn a total of five areas of potential environmental concern (APECs) at the site:

- APEC 1: associated with PCA of former printer;
- APEC 2: associated with PCA of historical gasoline service station;
- APEC 3: associated with PCA of former automotive service garage;
- APEC 4: associated with PCA of former dry cleaner; and
- APDC 5: associated with PCA of former BP petroleum products.

Paterson conducted Phase II ESA activities (subsurface investigation of soil and groundwater) to examine the APECs in June 2019 and September 2021, and reported the results of their investigation in October 2021 (Paterson, 2021):

- In June 2019, three boreholes (BH1, BH2, BH3) were drilled. Soil was sampled from each borehole at the time of drilling. All three boreholes were subsequently instrumented with groundwater monitoring wells, after which groundwater was sampled.
- In September 2021, two boreholes (BH4, BH5) were drilled. Soil was sampled from each borehole at the time of drilling. All three boreholes were subsequently instrumented with groundwater monitoring wells, after which groundwater was sampled. Groundwater was also sampled from the three previously installed wells.

Soil at the site is shallow (necessitating use of Table 7 site conditions standard (MECP, 2017), with a thin layer of topsoil (~0.36 m) of topsoil (or asphalt in the developed areas of the site), below which is native granular fill material (extending to depths of ~0.76 to 1.45 m below grade), below which is bedrock. Bedrock was encountered at an average depth of 1.15 m below the existing grade.

Groundwater levels vary between 4.16 and 5.34 m below grade (i.e., groundwater is found within the bedrock). Groundwater appears to flow in a northwesterly direction.

Soil and groundwater samples were submitted by Paterson to an external accredited laboratory. Based on the PCAs that were identified, Paterson directed the laboratory to analyze the samples for one or more of petroleum hydrocarbons (PHCs), BTEX (benzene/toluene/ethylbenzene/xylene), and volatile organic compounds (VOCs). Paterson analyzed the resulting laboratory data by screening all results against Ontario Ministry of the Environment, Conservation and Parks (MECP) Site Condition Standards (SCS). Specifically, Paterson selected Table 7 SCS (shallow soil, non-potable groundwater, residential land use, coarse-grain soil).

2. Human Health Risk Assessment

HHRA consists of the following four-step framework:

1. The first step is the Problem Formulation, which determines the objective and scope of the HHRA. The Problem Formulation is provided in Section 2.1.
2. The Toxicity Assessment step characterizes the *potential* health effects that are associated with exposure to a contaminant. The fundamental tenet of toxicology is that any chemical has the potential to elicit an adverse health effect if the level of exposure is high enough (or the receptor or exposure pathway is sensitive enough). Once the dose-response profile for a chemical has been characterized, then toxicological reference values (TRVs) can be established (typically by a health or environment regulatory agency). The TRV may, for example, be a “safe” or “acceptable” level of exposure to the chemical. The Toxicity Assessment for the contaminants at this site is described in detail in Section 2.2.
3. The Exposure Assessment step conservatively quantifies the amount of each contaminant a receptor is exposed to from all relevant exposure pathways, taking into account site-specific contaminant concentrations, fate-and-transport of the contaminant, and receptor-specific biological and behavioural characteristics that bring receptors into contact with contaminated media. The Exposure Assessment for this site is organized according to the two addresses that were assessed, and results are presented in Section 2.3.
4. The Risk Characterization integrates the results of the Exposure Assessment with the results of the Toxicity Assessment to generate quantitative estimates of risk. The Risk Characterization for this site is organized according to the two addresses that were assessed, and results are presented together with the Exposure Assessment results in Section 2.3.

2.1. Problem Formulation

2.1.1. HHRA Objectives

The objectives of the HHRA were to (i) assess health risks for human receptors that may be exposed to COCs at the Site, and (ii) recommend risk management measures in the form of site-specific risk-based objectives and/or other engineering and administrative controls for the Site.

2.1.2. HHRA Scope

The COCs in groundwater that have been identified on the basis of their maximum-detected concentrations exceeding MECP Table 7 SCS include the following: cis-1,2- dichloroethylene (cisDCE), tetrachloroethylene (PCE), trichloroethylene (TCE), and vinyl chloride (VC).

The main pathway of concern via which the groundwater COCs could pose a risk is if they turned into a vapour and migrated upwards through pore spaces in the soil, then intruded through cracks in the building floor slabs, and accumulated in indoor air to be inhaled by people. Details regarding how the indoor vapour intrusion pathway is quantitatively assessed are provided in the Exposure Assessment section of the HHRA.

An integrated representation of how environmental media and human receptors at the site are connected with one another are provided in the conceptual site model, or CSM (Figure 3). As shown in the CSM, other aspects of the HHRA that were assessed qualitatively include the following:

- Vapour contact pathway: This pathway's contribution to overall COC exposure is considered negligible in environmental (non-occupational) settings.
- Odour pathway: A dose-response relationship between nuisance odours and direct health impacts cannot be quantified. Odours arising from COCs would not be expected to adversely affect human health.
- Outdoor vapour pathways: Vapours that arise from groundwater and migrate upwards through soil to the *outdoor* air are considered to pose a negligible risk, as such vapours will be immediately dispersed and diluted by the ambient air (wind).
- Exposure of visitors to vapours: Any visitors to the site would be expected to be inside the buildings less frequently than the residents quantitatively assessed in this HHRA. If the HHRA determines that risk management measures are required to protect the health of residents, then by default those risk management measures will also be protective of the health of any people at the site less frequently.
- Trench vapour pathways: There are too many uncertainties to meaningfully quantitatively assess this pathway, as the extent to which vapours accumulate in a trench/excavation depends on both the dimensions (e.g., deep and narrow, vs wide and shallow, vs anything in between) and the orientation (e.g., parallel or perpendicular to the prevailing wind direction, or any intermediate angle) of the trench/excavation. Any trench/excavation work conducted by workers would need to be conducted in accordance with Ontario's occupational health and safety laws, which include provisions for respiratory health.
- Trench groundwater contact: Typical practice in HHRA is to assume that a construction / utility worker could possibly contact groundwater if they are working in a subsurface trench or excavation that intersects the groundwater table. This pathway was considered inapplicable at this site due to the groundwater level being metres below the bedrock.

2.2. Toxicity Assessment

The Toxicity Assessment step qualitatively and quantitatively characterizes the *potential* toxicity of each contaminant. The fundamental tenet of toxicology is that any chemical can cause toxicity (i.e., an adverse health response) if the exposure level (i.e., dose) is high enough (or equivalently if the receptor or exposure pathway is sensitive enough). The so-called dose-response relationship can be characterized by experimenting with laboratory animals (i.e., toxicological studies) or by observing naturally-exposed human populations (i.e., epidemiological studies).

A dose-response relationship will vary depending on: (i) the toxicological effect elicited by the chemical (e.g., cancer, non-cancer effects, or developmental toxicity); (ii) the toxicological mode of action of the chemical (i.e., threshold- or non-threshold-based); (iii) the receptor being exposed (e.g., child or adult); (iv) the pathway via which the receptor is exposed (e.g., oral or inhaled); and (v) the exposure duration (e.g., chronic, sub-chronic, or acute). Once a dose-response relationship has been characterized then it is possible to estimate a numerical value that in effect describes the toxicity of the chemical in humans in a way suitable for risk assessment (referred to as a toxicological reference value, or TRV).

Depending on how extensively a chemical has been toxicologically characterized, it may have multiple TRVs. For the purposes of risk assessment, an important distinction is made between TRVs that are developed to assess the risk of a receptor developing cancer (i.e., applicable to genotoxic carcinogens that act by a "non-threshold" mechanism of action), and TRVs that are developed to assess the risk of a receptor experiencing non-carcinogenic health effects (i.e., applicable to threshold-based toxicants). Each of these categories may in turn be sub-divided based on whether the TRV was derived for the oral pathway or the inhalation pathway.

The TRVs used by NovaTox in this HHRA are summarized in Table 2-1. As shown, all four COCs have the potential to cause adverse health effects unrelated to cancer. In addition, PCE, TCE and VC are considered carcinogens. Furthermore, TCE is considered a developmental toxicant.

Table 2-1: Human Health TRVs to Assess Threshold Health Effects

COC	TRV			Basis
	Type	Value	Units	
1,2-cis-Dichloroethylene	Threshold (inhalation)	1.5E-01	mg/m^3	MOE (2011) recommends a TRV of 1.5x10^{-1} mg/m^3, stating that it was "modified from" RIVM (2001). The TRV in RIVM (2001) is 3.0E-02 mg/m^3, which was derived by route-to-route extrapolation from an oral TRV of 6.0E-03 mg/kg-day (endpoint of decreased body weight and decreased hematocrit and hemoglobin in rats; McCauley et al., 1995). A MOECC (2017) policy document contains preferred TRVs for selected COCs, including 1,2-cis-dichloroethylene, with the recommended inhalation chronic non-cancer TRV being revised to a statement of "none selected". To be conservative, NovaTox is retaining the MOE (2011) recommended TRV so that inhalation hazards can be calculated for this compound.
Tetrachloroethylene	Non-threshold (inhalation)	2.6E-04	(mg/m^3)$^{-1}$	MOE (2011) TRV was superseded by a MOE guidance memorandum dated April 28, 2014. The recommended TRV is that developed by the U.S.EPA and listed on IRIS (2012). It is based on hepatocellular adenomas and carcinomas in mice and rats after inhalation exposure. U.S.EPA used a multistage model with linear extrapolation from the point of departure, followed by extrapolation to humans using a PBPK model.

COC	TRV			Basis
	Type	Value	Units	
	Threshold (inhalation)	4.0E-02	mg/m^3	MOE (2011) TRV was superseded by a MOE guidance memorandum dated April 28, 2014. The recommended TRV is that developed by the U.S.EPA and listed on IRIS (2012). It is based on multiple toxic effects to multiple systems (multiple points of departures and uncertainty factors) that support the final RfC.
Trichloroethylene	Non-threshold (inhalation)	4.1E-03	(mg/m^3)$^{-1}$	MOE (2011) TRV was superseded by a MOE guidance memorandum dated April 28, 2014. The recommended TRV is that developed by the U.S.EPA and listed on IRIS (2011). It is based on cancer of kidney and liver, and non-Hodgkin lymphoma, in humans after inhalation exposure (multiple epidemiology studies). U.S.EPA developed 3 IUR values for the 3 types of cancer, which were then summed.
	Threshold (inhalation)	2.0E-03	mg/m^3	MOE (2011) TRV was superseded by a MOE guidance memorandum dated April 28, 2014. The recommended TRV is that developed by the U.S.EPA and listed on IRIS (2011). It is based on multiple toxic endpoints, including developmental cardiotoxicity in rats. Multiple candidate RfC estimates derived using route-to-route extrapolation support the final RfC listed.
Vinyl chloride	Non-threshold (inhalation) (full-life)	8.8E-03	(mg/m^3)$^{-1}$	MOE (2011) recommends the TRV developed by the U.S.EPA and listed on IRIS (2000). It is based on cancer of liver in female rats after inhalation exposure (Maltoni et al., 1981, 1984). U.S.EPA calculated human-equivalent concentrations and also accounted for age-dependent sensitivities in developing 2 IUR values.
	Non-threshold (inhalation) (adult-only)	4.4E-03	(mg/m^3)$^{-1}$	
	Threshold (inhalation)	1.0E-01	mg/m^3	MOE (2011) recommends the TRV developed by the U.S.EPA and listed on IRIS (2000). A MOECC (2017) policy document contains preferred TRVs for selected COCs, including vinyl chloride, but the recommended inhalation chronic non-cancer TRV remained the same as MOE (2011) and continues to reference U.S.EPA (2000). The U.S.EPA (2000) Reference Concentration is based on studies in which rats were chronically exposed via the diet (Til et al., 1983, 1991). The critical endpoint was liver effects (liver cell polymorphism). U.S.EPA took a NOAEL of 0.13 mg/kg-day, converted it using PBPK modelling and route-to-route extrapolation to a human equivalent concentration (NOAEL$_{HEC}$) of 2.5 mg/m^3, then applied a total UF of 30 to arrive at the RfC.

Notes:
Bold/italic: Indicates TRV is based on developmental endpoints (i.e., implications for exposure assessment calculations).

2.3. Exposure Assessment and Risk Characterization

2.3.1. Estimation of Representative Groundwater Concentration

Groundwater COC concentrations reported in June 2019 and September 2021 are provided below in Table 2-1(a). As shown, there is a fair degree of variability in the data, with concentrations of each of the four COCs varying from less than the detection limit of 0.5 µg/L, to orders-of-magnitude exceedances of respective MECP Table 7 SCS.

Standard practice in regulatory RAs in support of a RSC under O. Reg. 153/04 is to conservatively assume that a reasonable estimate of the maximum (REM) concentration of each COC is representative of all the groundwater at the site. The REM is the observed maximum plus an additional 20%.

This RA will assess potential inhalation risks from the REM concentration, but will also consider the weight of evidence of *all* the reported groundwater data. It is unnecessarily conservative to assume that all groundwater at Winona Avenue contains COCs at their REM concentrations, given the observed variability. On this basis, boreholes were identified that could reasonably be assumed to potentially impact the 377 Winona address versus the 381 Winona address, and then the geometric mean concentration of each COC was calculated (refer to Table 2-1(b) and Table 2-1(c)) and carried through subsequent steps of the HHRA.

Table 2-1(a): COC Concentrations in Groundwater

COC	MECP Table 7 SCS (µg/L)	GW Conc. (µg/L)									
		BH1		BH2		BH3		BH4	BH5	Max.	REM
		2019	2021	2019	2021	2019	2021	2021	2021		
cisDCE	1.6	***13.7***	<0.5	***63.2***	***120***	***74.3***	***94.9***	***93***	<0.5	120	144
PCE	0.5	***35.8***	***5.6***	***150***	***155***	***418***	***144***	***122***	<0.5	418	502
TCE	0.5	***6.0***	<0.5	***31.6***	***55.8***	***15***	***44.1***	***42.1***	<0.5	55.8	67.0
VC	0.5	<0.5	<0.5	<0.5	<0.5	***0.8***	***7.1***	<0.5	<0.5	7.1	8.52
Note: - ***Bold/italic*** indicates exceedance of MECP Table 7 SCS. - BH3, BH4, and BH5 could reasonably be assumed to potentially impact the 377 Winona address. - BH1, BH2, and BH3 could reasonably be assumed to potentially impact the 381 Winona address.											

Table 2-1(b): COC Concentrations in Groundwater (377 Winona)

COC	GW Conc. (µg/L)					
	BH3			BH4	BH5	Geometric Mean of BH3, BH4, BH5
	2019	2021	Geometric Mean of BH3 results	2021	2021	
cisDCE	74.3	94.9	84.0	93	<0.5	15.7
PCE	418	144	245	122	<0.5	24.6
TCE	15	44.1	25.7	42.1	<0.5	8.15
VC	0.8	7.1	2.38	<0.5	<0.5	0.841

Table 2-1(c): COC Concentrations in Groundwater (381 Winona)

COC	GW Conc. (µg/L)									
	BH1			BH2			BH3			Geometric Mean of BH1, BH2, BH3
	2019	2021	Geo-mean of BH1 results	2019	2021	Geo-mean of BH2 results	2019	2021	Geo-mean of BH3 results	
cisDCE	13.7	<0.5	2.62	63.2	120	87.1	74.3	94.9	84.0	26.7
PCE	35.8	5.6	14.2	150	155	152	418	144	245	80.9
TCE	6.0	<0.5	1.73	31.6	55.8	42.0	15	44.1	25.7	12.3
VC	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8	7.1	2.38	0.841

2.3.2. Estimation of Representative Source Vapour Concentration

The second step in indoor vapour intrusion risk assessment is to calculate the concentration of vapour at the *source* of contamination, i.e., in the air of the pore spaces of the soil immediately overlying the groundwater table. This is accomplished by utilizing a chemical-specific parameter known as the Henry's Law Constant, (which is the equilibrium ratio between the chemical concentration in water and the chemical concentration in air) along with other site-specific and chemical-specific parameters specified by the Johnson and Ettinger (J&E) Model (1991), which is publicly available from the U.S. EPA (2004) and is described in detail in Appendix A.

Just as the groundwater concentrations of COCs are variable across the site, so too will be the source vapour concentrations immediately above the groundwater table. Source vapour concentrations for COCs are provided below in Table 2-2.

Table 2-2: Source Vapour Concentrations at Winona Avenue

	Source Vapour Conc. (mg/m³)		
COC	**REM**	**377 Winona**	**381 Winona**
cisDCE	15.9	1.74	2.95
PCE	215	10.6	34.7
TCE	17.0	2.07	3.12
VC	7.53	0.74	0.74
Note: - Source vapour concentrations calculated as specified by USEPA Johnson & Ettinger model, which is recommended by Ontario MECP. The parameter's groundwater concentration is multiplied by its respective Henry's Law Constant. If the parameter's groundwater concentration exceeds its aqueous solubility limit, then the solubility limit is multiplied by the Henry's Law Constant.			

2.3.3. Estimation of Attenuation Factor

The third step in indoor vapour intrusion risk assessment is to account for the extent to which source vapours are attenuated (i.e., diluted, or diminished in concentration) as the vapours (i) diffuse upwards through overlying soil (and in this case, a portion of which is bedrock; possibly fractured to some extent, (ii) undergo advective transport through cracks or other permeable areas of the building foundation, and (iii) are ultimately diluted by indoor air and normal building ventilation processes. The extent to which vapours are attenuated/diluted depends on soil characteristics (e.g., soil type, bulk density, porosity, permeability, among others), building characteristics (e.g., dimensions, foundation thickness, size of cracks in the foundation, air exchange rate, among others), and contaminant characteristics (e.g., depth to contamination) specific to the site.

Standard practice in regulatory RAs is to conservatively assume that the shallowest groundwater measurement is representative of all the groundwater at the site. At this site, the shallowest measurement has been reported as 4.16 m below grade. The calculated attenuation factor for vapours migrating from this depth is provided in Table 2-3. It is likely that despite the presence of the bedrock, there is moderate attenuation occurring at the vapours migrate upwards.

Table 2-3: Attenuation Factors for Vapour Intrusion at Winona Avenue

	Attenuation Factor (unitless)		
COC	REM	377 Winona	381 Winona
cisDCE	4.20E-04	4.20E-04	4.05E-04
PCE	4.10E-04	4.10E-04	3.96E-04
TCE	4.44E-04	4.44E-04	4.28E-04
VC	5.67E-04	5.67E-04	5.41E-04

Note:
- Attenuation factor calculated assuming groundwater depth of 416 cm (slab thickness of 8 cm, plus 29.9 cm thick layer of crushed gravel, plus 378.1 cm of additional distance between underside of slab and groundwater table. Assumed 377 Winona building dimensions of 15 m x 10 m. Assumed 381 Winona building dimensions of 21 m x 9 m. REM concentrations were modelled into the 377 Winona building. All other building characteristics set equal to generic residential slab-on-grade building. Soil type set as coarse/sand. Refer to Appendix A.

2.3.4. Estimation of Representative Indoor Vapour Concentration

The fourth step in indoor vapour intrusion risk assessment is to calculate an indoor vapour concentration, by multiplying the source vapour concentration(s) by appropriate attenuation factor(s). Results are presented in Table 2-4.

Table 2-4: Indoor Vapour Concentrations at Winona Avenue

	Indoor Vapour Conc. (mg/m^3)		
COC	REM	377 Winona	381 Winona
cisDCE	6.67E-03	7.29E-04	1.20E-03
PCE	8.82E-02	4.33E-03	1.37E-02
TCE	7.54E-03	9.18E-04	1.34E-03
VC	4.26E-03	4.21E-04	4.02E-04

2.3.5. Exposure Estimates

The fifth step in indoor vapour intrusion risk assessment is to account for the conditions or circumstances of exposure. That is, although the concentrations presented previously in Table 2-4 are the best estimates of vapour concentrations inside the building, the risk that those vapours pose to different people will vary. For example, intuitively, it is clear a hypothetical person inside a building for 24 hours per day, 365 days per year would have a much different risk from inhaling vapours than a person who is only inside a building for minutes per day intermittently through the year.

MECP provides standard exposure frequency assumptions for residents in regulatory RAs:

- Toddlers are assumed to be present inside their residence for 24 hours/day, 350 days/year.
- Full-life residents are assumed to be present inside their residence for 22.5 hours/day, 350 days/year.

Results are presented in Table 2-5.

Table 2-5: Exposure Estimates at Winona Avenue

COC	Pro-Rated Exposure Conc. (mg/m³)					
	REM		377 Winona		381 Winona	
	Toddler	Full-Life	Toddler	Full-Life	Toddler	Full-Life
cisDCE	6.39E-03	6.00E-03	6.99E-04	6.56E-04	1.15E-03	5.26E-13
PCE	8.45E-02	7.93E-02	4.15E-03	3.89E-03	1.32E-02	2.13E-10
TCE	7.54E-03	6.78E-03	9.18E-04	8.25E-04	1.34E-03	1.01E-12
VC	4.09E-03	3.83E-03	4.04E-04	3.79E-04	3.85E-04	5.89E-14

2.3.6. Risk Estimates

The sixth step in indoor vapour intrusion risk assessment is to divide each exposure estimate by its appropriate toxicological reference value to yield a hazard quotient (HQ) — and, for carcinogens, an incremental lifetime cancer risk (ILCR). Results are presented in Table 2-6.

Table 2-6: Risk Estimates at Winona Avenue

COC	REM		377 Winona		381 Winona	
	HQ	ILCR	HQ	ILCR	HQ	ILCR
cisDCE	0.04	–	0.005	–	0.008	–
PCE	***2.1***	***2.06E-05***	0.10	***1.01E-06***	***0.33***	***3.21E-06***
TCE	***3.8***	***2.78E-05***	0.46	***3.38E-06***	***0.67***	***4.93E-06***
VC	0.04	***3.37E-05***	0.004	***3.33E-06***	0.004	***3.18E-06***

Note:
- ***Bold/italic*** indicates exceedance of acceptable HQ (0.2, or in the case of TCE at a non-potable site, 0.5) or acceptable ILCR (1E-06).

3. Conclusions and Recommendations

3.1. Conclusions

Risk estimates obtained by using REM groundwater vapour concentrations indicates that three of the four COCs are calculated to pose a moderate to low potential risk: PCE, TCE, and VC. Risk exceedances are on the order of 10x to 30x the acceptable limits (refer to Table 2-7).

Risk estimates obtained by using geometric mean groundwater vapour concentrations near the 377 Winona address also indicates that three of the four COCs are calculated to pose a potential risk: PCE, TCE, and VC. Risk exceedances are marginal, at less than 4x acceptable limits (refer to Table 2-7).

Risk estimates obtained by using geometric mean groundwater vapour concentrations near the 381 Winona address also indicates that three of the four COCs are calculated to pose a potential risk: PCE, TCE, and VC. Risk exceedances are marginal, at less than 5x acceptable limits (refer to Table 2-7).

These are risk estimates that are calculated using very conservative approaches. In addition, these are very low risk estimates that are only marginally above the health-based limits when you factor in the geometric mean of the concentrations.

Table 2-7: Risk Reduction Required at Winona Avenue

COC	REM		377 Winona		381 Winona	
	Risk Reduction Required based on HQ	Risk Reduction Required based on ILCR	Risk Reduction Required based on HQ	Risk Reduction Required based on ILCR	Risk Reduction Required based on HQ	Risk Reduction Required based on ILCR
cisDCE	–	–	–	–	–	–
PCE	11	21	–	1.01	1.6	3.2
TCE	7.5	28	–	3.4	1.3	4.9
VC	–	34	–	3.3	–	3.2

3.2. Recommendations

Unacceptable risks have been *calculated*, but this does not necessarily mean that unacceptable risks are *actually* present or occurring. This is due to the conservative nature of preliminary quantitative HHRA methods and the conservatism that is inherent to the J&E model used to estimate indoor vapour concentrations.

Critically, the J&E model has no way to account for vapours migrating from a groundwater source beneath or significantly within *bedrock*. Guidance from other sources with regard to such vapour intrusion scenarios is also lacking. This preliminary HHRA has made the assumption that the results obtained by modelling coarse-grained sandy soil would approximate the conditions of the bedrock (e.g., extent of cracks and fracturing that would allow vapours to migrate upwards). However, there is a great deal of uncertainty in this assumption. It is recognized that the J&E model used to model and assess sub-surface vapour intrusion is conservative when assessing chlorinated VOCs.

The only practical way to address the assumption would be to perform an indoor air monitoring program, to determine the extent to which modelling reflects real-world conditions. As these are existing residential houses, an indoor air program could be completed to determine whether PCE, TCE and VC is present at sufficient levels to cause of unacceptable risk to occupants of the building. It is also feasible to instrument sub-slab vapour probes through the crawlspace floor and to collect vapour samples from beneath the grade. These concentrations can then be attenuated (using a default factor) to estimate what the potential air levels are within the actual building. This information can be used to further support a weight of evidence for the site and the assessment of potential health risks to building occupants.

4. Limitations

This report has been prepared and the work referred to in this report has been undertaken by NovaTox for Paterson Group Inc. on behalf of their client. It is intended for the sole and exclusive use of Paterson Group Inc. and their client. Any use, reliance on, or decision made by any person other than Paterson Group Inc. and their client based on this report is the sole responsibility of such other person. NovaTox makes no representation or warranty to any such other person with regard to this report and the work referred to in this report and accepts no duty of care to any person and any liability or responsibility whatsoever for any losses, expenses, damages, fines, penalties, or other harm that may be suffered or incurred by any other person as a result of the use of or reliance on any decision made or any action taken based on this report or the report of the work referred to in this report.

This report has been prepared for the exclusive use of Paterson Group Inc. and their client for specific application to the site. Any conclusions or recommendations made in this report reflect NovaTox's best judgment based on information available at the time of the report's preparation based, in part, on monitoring at various locations of the site, and specific analysis of specific chemical parameters and materials during a specific time interval, all as described in this report and other reports referenced herein.

Other than by Paterson Group Inc. and their clients, copying or distribution of this report or use of or reliance on the information contained herein, in whole or in part, is not permitted without the express written permission of NovaTox. Nothing in this report is intended to constitute or provide a legal opinion.

5. Closing

We trust the enclosed report satisfies your requirements at this time. If you have any questions or concerns, please contact the undersigned.

per,

NovaTox Inc.

Kevin Haines, MSc, DABT QP_{RA}
Senior Toxicologist

Christopher Marwood, PhD, QP_{RA}
Principal Toxicologist

Mark Chappel, MSc., DABT, QP_{RA}
Principal Toxicologist

Appendix 1
Human Health RA Calculations

Appendix A1: HHRA Input (A1(b): Groundwater COC Concentrations and Component Values)

NovaTox

				Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine
				Const. Worker	**Res.**		**Res.**	
				Incidental	**Indoor Air**	**Direct**	**Indoor Air**	
				“Contact”	**Inhalation**	**Odour**	**Odour**	**1/2-solubility**
Groundwater COC	**Maximum GW conc. (µg/L)**	**REM (µg/L)**	**Ontario Generic SCS (Table 7)**	**GW1 x 15**	**GW2**	**GW1-Odour**	**GW2-Odour**	**limit**
Dichloroethylene, 1,2-cis-	120	144	1.6	300	*1.6*	–	–	1,800,000
Tetrachloroethylene	418	502	0.5	*300*	*1.6*	*4.4E+02*	1.1E+06	100,000
Trichloroethylene	55.8	67.0	0.5	75	*1.6*	1.1E+03	2.4E+06	640,000
Vinyl Chloride (See table (iii) on the Appendix G1(b) sheet for calculation of nominal maximum)	7.1	8.52	0.5	30	*0.16*	5.3E+03	7.6E+06	4,400,000

Notes:

- Reasonable estimate of the maximum (REM) used for exposure and risk calculations and is the indicated maximum plus 20%.
- Ontario MECP Generic SCS are Table 7, for coarse soils.
- Other values are human health component values that factored into the derivation of the SCS (obtained from the MOE 2011 Rationale Document). If the component value is highlighted yellow, then it indicates the component value is exceeded by the REM.

- Component values not available for a construction worker contacting groundwater (e.g., while working in a trench or excavation). A reasonable estimate is that a worker would incidentally ingest 0.15 L of groundwater per day. This is approximately 1/15th the rate of potable water ingestion by an adult (2.3 L /day). Therefore the GW1 value was adjusted upwards by a factor of 15 for screening purposes for a construction worker.
- If a COC was identified as only requiring assessment via one pathway (e.g., contact or inhalation) it was nonetheless conservatively also assessed via the other pathway if possible (i.e., it was assessed via both contact and inhalation). This was for comprehensiveness and ease of RA preparation and review (i.e., the same groundwater COC list is maintained throughout each table of the exposure assessment and risk characterization sections). In this regard, all COCs identified as requiring quantitative assessment were conservatively assessed via pathways for which no component values are available (e.g., construction worker exposure to vapours while in a trench or excavation; exposure to groundwater vapours in outdoor air).

Site Characteristics				
Category	**Site Characteristic**	**Symbol**	**Units**	**Value**
Water Potability	Potability of groundwater		–	Non-Potable
J&E Building Inputs	Type of Building		–	Residential Slab-on-Grade
	Length		cm	1,500
	Width		cm	1,000
	Height (of mixing zone)		cm	366
	Slab Thickness	Lcrack	cm	8
	Depth below grade to bottom of floor	L_F	cm	8
	Crack depth below grade	X_{crack} or Z_{crack}	cm	8
	Crack Width	w	cm	0.1
	Pressure Differential, Building - Soil	Δp	g/cm-sec2	40
	Air Exchange Rate	ER	1/hour	0.3
	Flow rate of soil vapour into building (or leave blank)	Q_{SOIL}	L/min	8.45
	Floor-wall seam perimeter	X_{crack}	cm	5,000
	Building ventilation rate	$Q_{building}$	cm^3/s	4.58E+04
	Area of enclosed space below grade	A_B	cm^2	1.50E+06
	Crack-to-total area ratio	η	–	3.33E-04
J&E GW Inputs	Depth below grade to contaminated GW	zgw or L_{WT}	cm	416.00
	Depth to contaminated GW used in indoor model	zgw or L_{WT}	cm	416.00
	GW Source-bldg. separation	L_T	cm	408.00
	Soil Stratum A - Thickness	h_A	cm	8
	Soil Stratum B - Thickness (GW model)	h_B	cm	29.90
	Soil Stratum C - Thickness (GW model)	h_C	cm	378.10
	Soil stratum directly above water table	–	–	C
	SCS soil type directly above water table	–	–	Sand
	Capillary zone thickness	L_{CZ}	cm	17.045
	Capillary zone total porosity	n_{CZ}	cm^3/cm^3	0.375
	Capillary zone water-filled porosity	$\theta_{w,cz}$	cm^3/cm^3	0.253
	Capillary zone air-filled porosity	$\theta_{a,cz}$	cm^3/cm^3	0.122

Lookup Table (i)				
Building Characteristics	**Residential Building-with-Basement**	**Residential Slab-on-Grade**	**Commercial Building-with-Basement**	**Commercial Slab-on-Grade**
Depth below grade to bottom of floor (a)	158	8	161.25	11.25
Length (a)	1,225	1,500	2,000	2,000
Width (a)	1,225	1,000	1,500	1,500
Height (a)	366	366	300	300
Slab Thickness (a)	8	8	11.25	11.25
Crack Width (a)	0.1	0.1	0.1	0.1
Pressure Differential, Building - Soil (a)	40	40	20	20
Air Exchange Rate (a)	0.3	0.3	1	1
Crack depth below grade (a)	158	8	161.25	11.25
Flow rate of soil vapour into building (a)	8.45	8.45	9.80	9.80
Floor-wall seam perimeter (b)	4,900	5,000	7,000	7,000
Building ventilation rate (b)	4.58E+04	4.58E+04	2.50E+05	2.50E+05
Area of enclosed space below grade (b)	2.27E+06	1.50E+06	4.13E+06	3.00E+06
Crack-to-total area ratio (b)	2.15E-04	3.33E-04	1.70E-04	2.33E-04

Notes:
- Residential building-with-basement and commercial slab-on-grade buildings are MECP default building types.
- Commercial building-with-basement assumed to be same dimensions and characteristics as commercial slab-on-grade building, but with a basement that extends to 150 cm (i.e., same as residential building-with-basement), and a default commercial slab thickness of 11.25 cm, for a total depth to bottom of floor of 161.25 cm.
- Residential slab-on-grade building assumed to be same dimensions and characteristics as residential building-with-basement, but no basement means that the total depth below grade to bottom of floor is 8 cm.

(a) MECP default values.
(b) Calculated per J&E model equation.

Appendix A1: HHRA Input (A1(c): Site Characteristics)

J&E Soil Stratum A Parameters	Stratum A SCS soil type			Sand
	Stratum A soil total porosity	n^A	–	0.375
	Stratum A water filled porosity	θ_W^A	cm^3/cm^3	0.054
	Stratum A soil air-filled porosity	θ_a^A	cm^3/cm^3	0.321
	Stratum A soil dry bulk density	ρ_b^A	g/cm^3	1.66
	Stratum A soil organic carbon fraction	f_{OC}^A	–	0.005
	User defined stratum A soil vapour permeability	k_V	cm^2	
	Stratum A effective total fluid saturation	S_{te}	cm^3/cm^3	0.003
	Stratum A soil intrinsic permeability	k_i	cm^2	1.00E-07
	Stratum A soil relative air permeability	k_{rg}	cm^2	0.998
	Stratum A soil effective vapour permeability	k_v	cm^2	9.99E-08
J&E Soil Stratum B Parameters	Stratum B SCS soil type			Gravel Crush
	Stratum B soil total porosity	n^B	–	0.400
	Stratum B water filled porosity	θ_W^B	cm^3/cm^3	0.010
	Stratum B soil air-filled porosity	θ_a^B	cm^3/cm^3	0.390
	Stratum B soil dry bulk density	ρ_b^B	g/cm^3	1.60
	Stratum B soil organic carbon fraction	f_{OC}^B	–	0.000
J&E Soil Stratum C Parameters	Stratum C SCS soil type			Sand
	Stratum C soil total porosity	n^C	–	0.375
	Stratum C water filled porosity	θ_W^C	cm^3/cm^3	0.054
	Stratum C soil air-filled porosity	θ_a^C	cm^3/cm^3	0.321
	Stratum C soil dry bulk density	ρ_b^C	g/cm^3	1.66
	Stratum C soil organic carbon fraction	f_{OC}^C		0.005
J&E Miscellaneous Parameters	Soil/Groundwater temperature		°C	15
	Exposure duration		y	56
	Exposure duration	τ	s	1.77E+09
	Conversion factor	C	cm^3-kg/m^3-g	1,000

Lookup Table (ii)

Soil Properties

SCS Soil Type	K_s (cm/h)	α_1 (1/cm)	N (unitless)	M (unitless)	n (cm³/ cm³)	θ_r (cm³/ cm³)	Mean Grain Diameter (cm)	Bulk density (g/cm³)	θ_w (cm³/ cm³)	f_{OC}	SCS Soil Name	Texture
C	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092	1.43	0.215	0.005	Clay	fine
CL	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016	1.48	0.168	0.005	Clay Loam	fine
L	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020	1.59	0.148	0.005	Loam	medium
LS	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040	1.62	0.076	0.005	Loamy Sand	coarse
Gravel Crush	36,000		5.000	0.8000	0.400	0.010	1.000	1.60	0.010	0.000	Gravel Crush	
Sand	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044	1.66	0.054	0.005	Sand	coarse
SC	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025	1.63	0.197	0.005	Sandy Clay	medium
SCL	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029	1.63	0.146	0.005	Sandy Clay Loam	medium
SI	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046	1.35	0.167	0.005	Silt	medium
SIC	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039	1.38	0.216	0.005	Silty Clay	fine
SICL	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056	1.37	0.198	0.005	Silty Clay Loam	fine
SIL	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011	1.49	0.180	0.005	Silt Loam	medium
SL	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030	1.62	0.103	0.005	Sandy Loam	coarse

Notes:

- Ks = hydraulic conductivity (does not actually factor into model calculations)
- α1 = van Genuchten point of inflection in the water retention curve (does not actually factor into model calculations)
- N = van Genuchten curve shape parameter (essentially the ability of soil to retain water; higher value = less retention)
- M = van Genuchten parameter = 1 - (1/N)
- n = total porosity
- θr = residual water content (factors into the calculation of θw)
- θw = water-filled porosity
- fOC = fraction organic carbon
- Values for the 12 SCS soil types obtained from J&E model
- Values for gravel crush obtained from MECP guidance memorandum: Ks, n, θw, bulk density
- Value for gravel crush assumed by NovaTox: N (higher value than soil = less retention of water than soil)
- Value for gravel crush assumed by NovaTox: mean grain diameter (assumed 1 cm diameter of typical piece of gravel)
- Value for gravel crush assumed by NovaTox: fOC

Appendix A1: HHRA Input (A1(d): COC Physical-Chemical Properties and Relative Absorption Factors)

COC Physical & Chemical Properties															
COC	**Mol wt. (g/mol)**	**Log K_{OW}**	**Vapour pressure (mm Hg)**	**Max theoretical vapour conc. in a headspace (ppm)**	**Max theoretical vapour conc. in a headspace (mg/m3)**	**Henry's Law constant at ref. temp, H (atm-m^3/mol)**	**Henry's Law constant, H (unitless)**	**K_{OC} (cm^3/g)**	**Diffusivity in air, D_a (cm^2/s)**	**Diffusivity in water, D_w (cm^2/s)**	**Aqueous solubility (mg/L)**	**Boiling point, T_B (°K)**	**Critical temp., T_C (°K)**	**Enthalpy of vaporization, DH_{vb} (cal/mol)**	**Density (g/cm^3)**
Dichloroethylene, 1,2-cis-	9.69E+01	2.09E+00	2.01E+02	2.64E+05	1.05E+06	4.09E-03	1.67E-01	8.76E+01	7.36E-02	1.13E-05	3.50E+03	3.34E+02	5.44E+02	7.19E+03	1.28E+00
Tetrachloroethylene	1.66E+02	3.40E+00	1.85E+01	2.43E+04	1.65E+05	1.77E-02	7.24E-01	2.14E+02	7.20E-02	8.20E-06	2.06E+02	3.94E+02	6.20E+02	8.29E+03	1.62E+00
Trichloroethylene	1.31E+02	2.42E+00	6.90E+01	9.08E+04	4.86E+05	9.86E-03	4.03E-01	1.35E+02	7.90E-02	9.10E-06	1.28E+03	3.60E+02	5.44E+02	7.51E+03	1.46E+00
Vinyl Chloride	6.25E+01	1.62E+00	2.98E+03	3.92E+06	1.00E+07	2.79E-02	1.14E+00	4.75E+01	1.06E-01	1.23E-06	8.80E+03	2.59E+02	4.32E+02	5.25E+03	9.11E-01

Notes:
- Non-highlighted cells from MGRA model (MOE 2011).
- Yellow highlighted cells from J&E model (Feb. 2004).

Relative Absorption Factors						
COC	**MOE RAF Soil Oral**	**MOE RAF Soil Dermal**	**MOE RAF Water Oral**	**MOE RAF Water Dermal**	**RAGS FA Water Dermal**	**MOE RAF Inhalation**
Dichloroethylene, 1,2-cis-	1	0.03	1	1		1
Tetrachloroethylene	1	0.03	1	1	1	1
Trichloroethylene	1	0.03	1	1	1	1
Vinyl Chloride	1	0.03	1	1	1	1

Inhalation of vapours arising from soil and/or groundwater COCs and migrating to indoor air is considered a complete exposure pathway for receptors who spend the majority of their time indoors. Indoor vapour concentrations are estimated using the Johnson and Ettinger (J&E) subsurface vapour intrusion model (Johnson and Ettinger 2001), which is generally accepted and recommended by the scientific community as well as the Ontario MECP and many other regulatory communities, and is publicly available from the U.S. EPA (Version 3.1; US EPA 2004). The model calculates the concentration of COC vapour at the contaminant source in different ways, depending on whether the COC source is in soil or groundwater. The model then converts this maximum “source vapour” concentration to a reduced “indoor vapour” concentration by accounting for the attenuation that occurs as the vapour (i) diffuses through soil, (ii) undergoes advective transport through cracks or other permeable areas of the building foundation, and (iii) is ultimately diluted by indoor air and normal building ventilation processes. Site-specific soil- and building- characteristics can be accounted for in the model. The J&E models for predicting indoor vapour concentrations from soil and groundwater sources are summarized in the equations below. Both equations have been adapted to include a bio-attentuation factor (as allowed by MECP; described below); in addition, the soil equation has been adapted to include a source-depletion multiplier term (as allowed by MECP; described below). Indoor vapour concentrations are pro-rated for a receptor’s exposure frequency and duration as shown.

Equation for Calculating Effective Exposure Concentration of COC Vapour in Indoor Air

$$C_{\text{effective-indoor}} = C_{\text{indoor air}} \times \frac{\text{hours}}{24} \times \frac{\text{days}}{365}$$

Where:
$C_{\text{effective indoor}}$ = Effective exposure concentration of COC in indoor air (µg/m^3)
$C_{\text{indoor air}}$ = COC concentration in indoor air (µg/m^3)
hours = Hours per day exposed to the vapours
days = Days per year exposed to the vapours

Note: for assessment of carcinogenic risks, an additional exposure adjustment factor is applied: $\left(\frac{\text{years exposed}}{\text{amortization period}}\right)$

Equation for predicting indoor vapour concentration from soil contamination

$$C_{\text{indoor air}} = C_{\text{soil}} \times \left(\frac{H \times B \times CF1}{\theta_{\text{water}} + (Koc \cdot foc) \times B + H \times \theta_{\text{air}}}\right) \times \alpha \times BAF \times \frac{1}{SDM}$$

Equation for predicting indoor vapour concentration from groundwater contamination

$$C_{\text{indoor air}} = C_{\text{gw}} \times (H \times CF2) \times \alpha \times BAF$$

Where:
$C_{\text{indoor-air}}$ = COC concentration in indoor air (µg/m^3)
C_{soil} = COC concentration in soil (µg/g)
C_{gw} = COC concentration in groundwater (µg/L)
H = Henry's Law coefficient (unitless)
B = Soil bulk density (g/cm^3)
CF1 = Conversion factor (10^6 cm^3/m^3)
CF2 = Conversion factor (10^3 L/m^3)
θ_{air} = Air-filled soil porosity (unitless)
θ_{water} = Water-filled soil porosity (unitless)
K_{oc} = Organic carbon-water sorption coefficient (cm^3-water/g-carbon)
f_{oc} = Fraction organic carbon
α = attenuation factor (unitless)
BAF = bio-attenuation factor (unitless)
SDM = source depletion multiplier (unitless)

Attenuation Factor

The attenuation factor, alpha (α), is calculated by the J&E model using the following equation. It is as shown in Section 7.3.3 of the MOE (2011) Rationale Document. NovaTox notes the following:

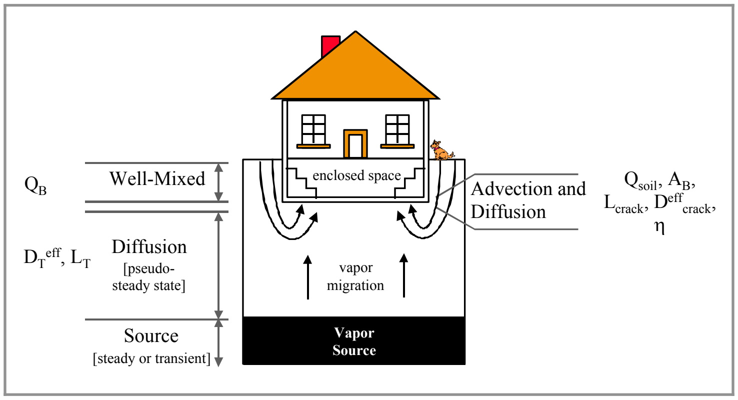
- *Soil vapour modelling*: Always uses attenuation factors as calculated by the J&E model.
- *Groundwater vapour modelling*: There is some uncertainty regarding the approach to be used during groundwater vapour modelling. According to Section 7.6.3 of the MOE (2011) Rationale Document, attenuation factors calculated by the J&E model are to be used in instances where groundwater is *beneath* the gravel crush, while conservative default attenuation factors (0.02 for residential buildings and 0.004 for commercial buildings) are to be used in instances where groundwater is *penetrating* the gravel crush. However, according to a MOECC (2018) MGRA Tool Training Manual, the conservative default attenuation factors are to be used in instances where there is a "separation distance < 1 m" between the groundwater and the concrete slab/foundation of the building. NovaTox is following the MOECC (2018) recommendation as it is more conservative than the MOE (2011) recommendation.

Equation for calculating attenuation factor

$$\alpha = \frac{\left(\frac{D_T * A_B}{Q_{building} * L_T}\right) * \exp\left(\frac{Q_{soil} * L_{crack}}{D_{crack} * A_{crack}}\right)}{\left(\exp\left(\frac{Q_{soil} * L_{crack}}{D_{crack} * A_{crack}}\right) + \left(\frac{D_T * A_B}{Q_{building} * L_T}\right) + \frac{D_T * A_B}{Q_{soil} * L_T} * \left[\exp\left(\frac{Q_{soil} * L_{crack}}{D_{crack} * A_{crack}}\right) - 1\right]\right)}$$

Where:
α = attenuation factor (unitless)
L_T = Distance from building to source of contamination (cm)
L_{crack} = Thickness of floor/building foundation/concrete slab (cm)
A_B = Area of the building below grade (i.e., floor plus 4 walls) (cm^2)
A_{crack} = Area of total cracks in A_B (cm^2)
D_T = Diffusion coefficient for soil (total overall coefficient, which takes into account varying diffusion through different soil types) (cmP^{2}P/secP)
D_{crack} = Diffusion coefficient for floor/cracks (assumed to be equivalent to diffusion coefficient of the soil type closest to the floor) (cm^2/sec)
Q_{soil} = Flow rate of soil vapour into the building (cm^3/s)
$Q_{building}$ = Flow rate of outdoor air into the building (i.e., ventilation rate) (cm^3/sec)

A conceptual diagram showing vapour migration from a source of subsurface contamination to indoor air (and also shows the processes/system components/inputs required for calculation of the attenuation factor) is shown in the figure below (taken from Johnson 2002).



Bio-Attenuation Factor

Ontario MECP allows for the application of a bio-attenuation factor (BAF) to account for certain contaminants (naphthalene, BTEX, PHC F1/F2, hexane) being susceptible to biodegradation as they migrate as a vapour through aerobic soil. BAFs can be briefly summarized as follows:

- *Soil vapour modelling*: If there is at least 1 m of clean fill between the soil contamination and the underside of the crushed gravel layer under the building, then a BAF of 0.1 can be applied. If there is at least 3 m of clean fill, then the BAF can be 0.01. (Reference: Section 7.4.6 of the MOE (2011) Rationale Document).

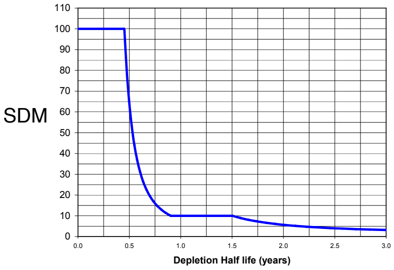
- *Groundwater vapour modelling*: If there is at least 0.74 m of *unsaturated* clean fill (vadose zone soil) between the top of the saturated capillary zone and the underside of the crushed gravel layer under the building, then a BAF of 0.1 can be applied. If there is at least 3 m of unsaturated clean fill, then the BAF can be 0.01. (Reference: Section 7.6.3 of the MOE (2011) Rationale Document).

Source Depletion Multiplier

Ontario MECP allows for the application of a source depletion multiplier (SDM) to account for the fact that a finite contaminant source in soil will progressively deplete over time as the contaminant volatilizes away (i.e., simple mass balance rationalization). SDMs can be briefly summarized as follows:

- *Soil vapour modelling*: A SDM value depends on how rapidly a contaminant source depletes, i.e., is a function of the contaminant's depletion *half-life*. A contaminant's allowable SDM exponentially declines as its half-life increases: the continuous range of "theoretical" SDM values is approximated by MECP by using (i) a default maximum SDM of 100 for contaminants with a high rate of depletion (i.e., a short half-life, assumed by MECP to be ≤0.4515 years), (ii) an exponential decay equation for contaminants with half-lives between >0.4515 years and <0.905 years, (iii) a default SDM value of 10 for contaminants with half-lives between 0.905 years and <1.505 years, and (iv) another exponential decay equation for contaminants with half-lives ≥1.505 years. The depletion half-life is calculated by MECP by taking into account the initial mass of the contaminant source (found in a default volume of soil of 13m x 13m x 2m, minus the volume of soil that must be excavated to allow placement of a building[*]), and the mass of contaminant that remains after 1 week of depletion/volatilization. The 1-week half-life is subsequently extrapolated to an annual half-life. (Reference: Section 7.4.4, subsections (3) through (8) of the MOE (2011) Rationale Document).

- *Groundwater vapour modelling*: Does not allow application of a SDM due to the difficulties in estimating a contaminant source mass in groundwater. (Reference: Section 7.3.5.1 of the MOE (2011) Rationale Document).



---

[*] For the purposes of calculating the SDM, NovaTox assumes that the maximum dimensions of soil that can possibly be excavated for placement of a building are 12.99m x 12.99m x 1.99m. Otherwise a SDM may not be able to be calculated at all in certain instances (e.g., a site-specific building with dimensions that exceed 13m x 13m x 2m).

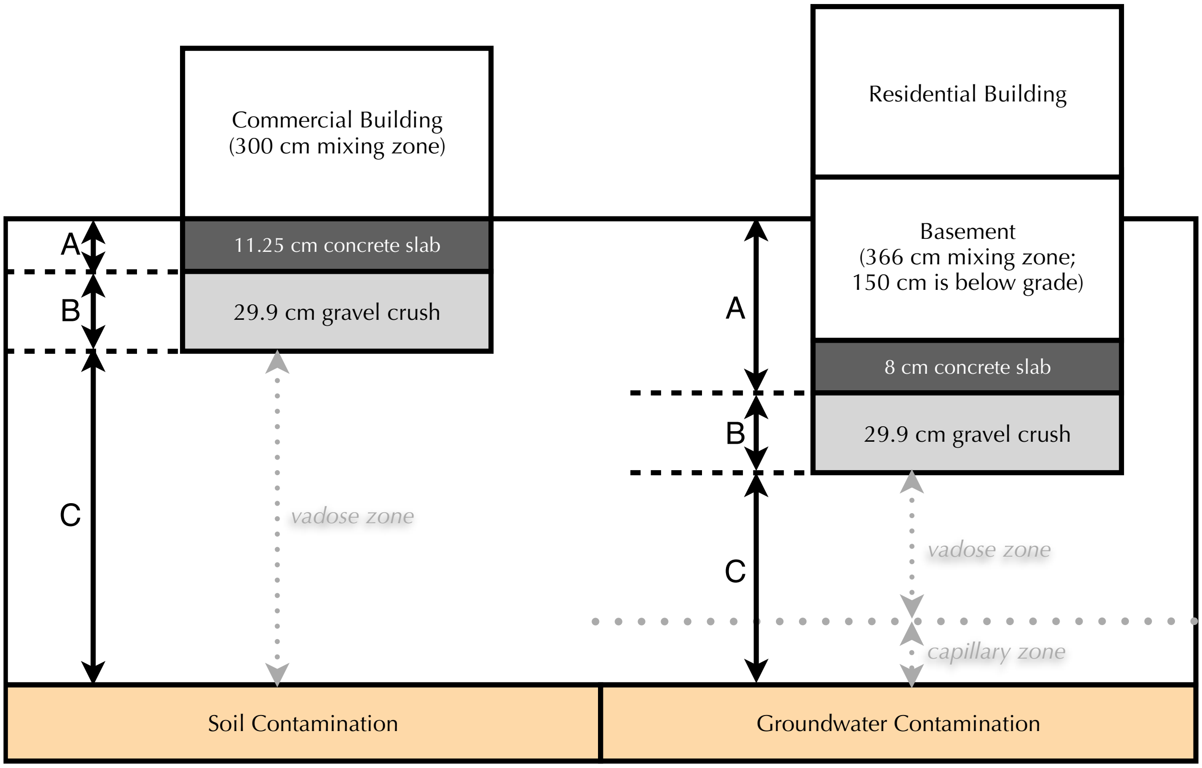
Building Proximity to Contaminant Source

With regard to the building's proximity to subsurface sources of contamination and the soil layers / "strata" required by the J&E model:

- "Soil Stratum A" represents the layer of soil extending from the surface to the underside of the concrete foundation slab (11.25 cm for "generic" commercial slab-on-grade buildings; 158 cm for "generic" residential buildings with basements). The default soil "type" is typically *sand* (i.e., the most conservative type, which is associated with the highest potential for vapours to migrate through the soil and into the building).

- "Soil Stratum B" represents the layer of crushed gravel under the foundation (required by the Ontario Building Code and in turn therefore required in J&E modelling per MECP guidance). In the soil model it has a full thickness of 29.9 cm. In the groundwater model its effective thickness is anywhere from 0.1 cm to 29.9 cm (i.e., anything less than the full thickness of 29.9 cm represents groundwater penetrating the gravel).

- "Soil Stratum C" represents the layer of soil / clean fill between the contaminant source and the underside of the crushed gravel. The default soil type is typically sand. In the soil model, the entirety of this layer is vadose zone soil (i.e., unsaturated). In the groundwater model, this layer consists of vadose zone soil as well as capillary zone soil immediately above the groundwater table (i.e., saturated due to water being drawn into pore spaces due to capillary action).



Building Characteristics

Ontario MECP provides default characteristics for a "generic" commercial slab-on-grade scenario and a "generic" residential building-with-basement scenario. Those default characteristics were also used by NovaTox to derive a "generic" commercial building-with-basement scenario and a "generic" residential slab-on-grade scenario.

Building Characteristics	**Residential Building-with-Basement**	**Residential Slab-on-Grade**	**Commercial Building-with-Basement**	**Commercial Slab-on-Grade**
Depth below grade to bottom of floor (a)	158	8	161.25	11.25
Length (a)	1,225	1,225	2,000	2,000
Width (a)	1,225	1,225	1,500	1,500
Height (a)	366	366	300	300
Slab Thickness (a)	8	8	11.25	11.25
Crack Width (a)	0.1	0.1	0.1	0.1
Pressure Differential, Building - Soil (a)	40	40	20	20
Air Exchange Rate (a)	0.3	0.3	1	1
Crack depth below grade (a)	158	8	161.25	11.25
Flow rate of soil vapour into building (a)	8.5 (coarse soil) 1.0 (fine soil)	8.5 (coarse soil) 1.0 (fine soil)	9.8 (coarse soil) 1.5 (fine soil)	9.8 (coarse soil) 1.5 (fine soil)
Floor-wall seam perimeter (b)	4,900	4,900	7,000	7,000
Building ventilation rate (b)	4.58E+04	4.58E+04	2.50E+05	2.50E+05
Area of enclosed space below grade (b)	2.27E+06	1.50E+06	4.13E+06	3.00E+06
Crack-to-total area ratio (b)	2.15E-04	3.27E-04	1.70E-04	2.33E-04

Notes:
- Residential building-with-basement and commercial slab-on-grade buildings are MECP default building types.
- Commercial building-with-basement assumed to be same dimensions and characteristics as commercial slab-on-grade building, but with a basement that extends to 150 cm (i.e., same as residential building-with-basement), and a default commercial slab thickness of 11.25 cm, for a total depth to bottom of floor of 161.25 cm.
- Residential slab-on-grade building assumed to be same dimensions and characteristics as residential building-with-basement, but no basement means that the total depth below grade to bottom of floor is 8 cm.

(a) MECP default values.
(b) Calculated per J&E model equation.

Soil Characteristics

The Soil Conservation Service (SCS) of the U.S. Department of Agriculture (USDA) provides default characteristics for 12 different "types" of soil that have varying compositions of sand, silt, and clay. Ontario MECP provides default characteristics for crushed gravel. Characteristics relevant to the migration of vapours through soil have been encoded into the J&E model.

Soil Properties										
SCS Soil Type	**K_s (cm/h)**	**α_1 (1/cm)**	**N (unitless)**	**M (unitless)**	**n (cm^3/ cm^3)**	**θ_r (cm^3/ cm^3)**	**Mean Grain Diameter (cm)**	**Bulk density (g/cm^3)**	**θ_w (cm^3/ cm^3)**	**f_{OC}**
Clay	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092	1.43	0.215	0.005
Clay Loam	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016	1.48	0.168	0.005
Loam	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020	1.59	0.148	0.005
Loamy Sand	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040	1.62	0.076	0.005
Gravel Crush	36,000				0.400		1.000	1.60	0.010	
Sand	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044	1.66	0.054	0.005
Sandy Clay	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025	1.63	0.197	0.005
Sandy Clay Loam	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029	1.63	0.146	0.005
Silt	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046	1.35	0.167	0.005
Silty Clay	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039	1.38	0.216	0.005
Silty Clay Loam	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056	1.37	0.198	0.005
Silt Loam	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011	1.49	0.180	0.005
Sandy Loam	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030	1.62	0.103	0.005

Notes:
- Ks = hydraulic conductivity (does not actually factor into model calculations)
- α_1 = van Genuchten point of inflection in the water retention curve (does not actually factor into model calculations)
- N = van Genuchten curve shape parameter (essentially the ability of soil to retain water; higher value = less retention)
- M = van Genuchten parameter = 1 - (1/N)
- n = total porosity
- θr = residual water content (factors into the calculation of θw)
- θw = water-filled porosity
- f_{OC} = fraction organic carbon
- Values for the 12 SCS soil types obtained from J&E model
- Values for gravel crush obtained from MECP guidance memorandum: Ks, n, θw, bulk density
- Value for gravel crush assumed by NovaTox: mean grain diameter (assumed 1 cm diameter of typical piece of gravel)

References

Johnson, P. C. 2002. Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model. American Petroleum Institute Bulletin No. 17, Washington, DC.

Johnson, P. C. and R. A. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors in buildings. Environ. Sci. Technol. 25: 1445-1452.

U.S. EPA. 2004. Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings. Models and user's guide available for download from: http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm. United States Environmental Protection Agency, Office of Emergency and Remedial Response.

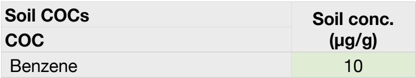
<u>Note:</u>

NovaTox has re-created the J&E models publicly available from the U.S. EPA (Version 3.1; US EPA 2004) in its own proprietary model. All input parameters (i.e., the U.S. EPA "DATENTER" sheets), and all intermediate calculations and final output (i.e., the U.S. EPA "INTERCALCS" sheets) are fully accounted for in NovaTox's model.

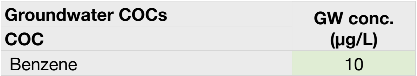
As a quality assurance / quality control measure, the following pages compare NovaTox's J&E model to U.S. EPA's J&E models, using benzene as an example contaminant. Vapour intrusion was modelled as follows:

- Benzene in soil at a concentration of 10 µg/g, and from a depth of 100 cm below grade.
- Benzene in groundwater at a concentration of 10 µg/L, and from a depth of 100 cm below grade.
- The soil and groundwater models each assessed a <u>commercial slab-on-grade building</u>, with generic parameters as defined by MECP.

Appendices G1(a) and G1(b) of the RA provide concentrations of COCs in soil and groundwater, respectively. Benzene is shown below as an example. Contaminant concentrations are typically entered on the "DATENTER" sheets of the EPA J&E models.



Soil COCs COC	Soil conc. (µg/g)
Benzene	10



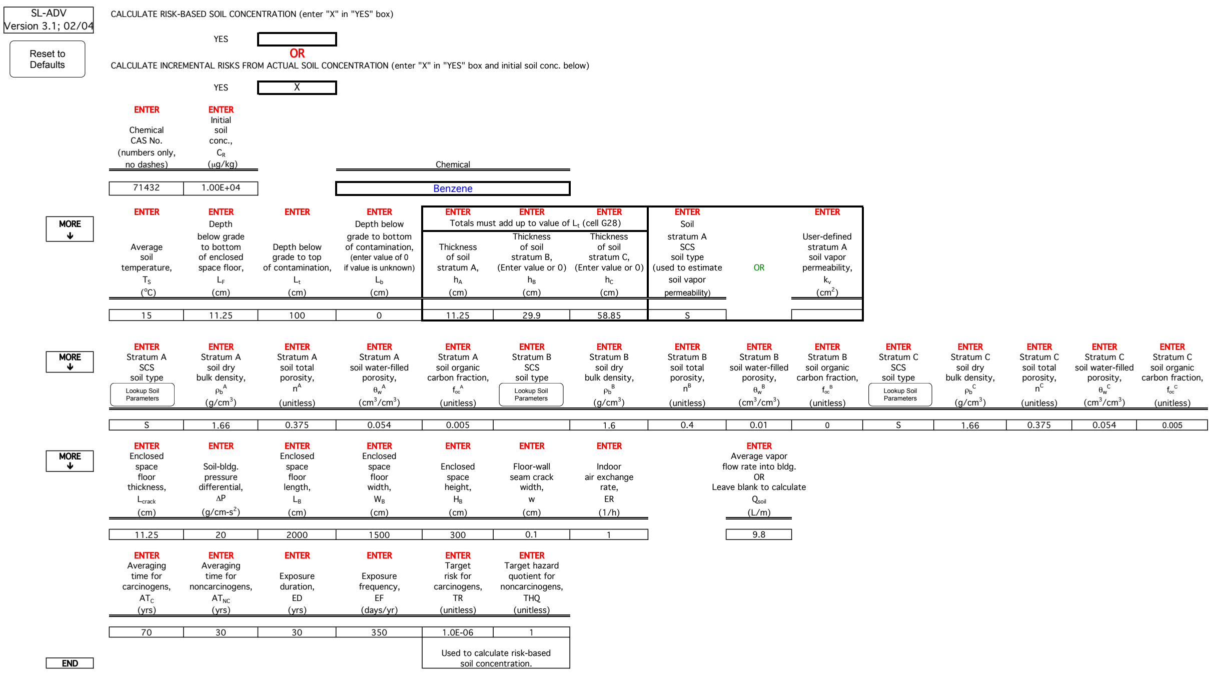
Groundwater COCs COC	GW conc. (µg/L)
Benzene	10

Appendix G1(c) of the RA provides input parameters specific to the site (e.g., depth to contamination, soil strata characteristics, building characteristics, etc). An example is shown on the following page. These inputs are typically entered on the "DATENTER" sheets of the EPA J&E models.

Category	Site Characteristic	Symbol	Units	Value
Water Potability	Potability of groundwater		–	Potable
J&E Building Inputs	Type of Building		–	Commercial Slab-on-Grade
	Slab Thicknss	Lcrack	cm	11.25
	Depth below grade to bottom of floor	L_F	cm	11.25
J&E Soil Inputs	Depth below grade to top of contaminated soil	zsoil or L_t	cm	100
	Depth to contaminated soil used in model	zsoil or L_t	cm	100
	Soil Source-bldg. separation	L_T	cm	88.75
	Depth below grade to bottom of contaminated soil	L_b	cm	0
	Soil Stratum A - Thickness	h_A	cm	11.25
	Soil Stratum B - Thickness (Soil model)	h_B	cm	29.9
	Soil Stratum C - Thickness (Soil model)	h_C	cm	58.9
J&E GW Inputs	Depth below grade to contaminated GW	zgw or L_{WT}	cm	100.00
	Depth to contaminated GW used in model	zgw or L_{WT}	cm	100.00
	GW Source-bldg. separation	L_T	cm	88.75
	Soil Stratum A - Thickness	h_A	cm	11.25
	Soil Stratum B - Thickness (GW model)	h_B	cm	29.9
	Soil Stratum C - Thickness (GW model)	h_C	cm	58.9
	Soil stratum directly above water table	–	–	C
	SCS soil type directly above water table	–	–	Sand
Building Characteristics	Length		cm	2000
	Width		cm	1500
	Height		cm	300
	Crack Width	w	cm	0.1
	Pressure Differential, Building - Soil	Δp	g/cm-sec2	20
	Air Exchange Rate	ER	1/hour	1
	Crack depth below grade	$X_{crack\ or\ Zcrack}$	cm	11.25
	Flow rate of soil vapour into building (or leave blank)	Q_{SOIL}	L/min	9.8
	Floor-wall seam perimeter	X_{crack}	cm	7,000
	Building ventilation rate	$Q_{building}$	cm^3/s	2.50E+05
	Area of enclosed space below grade	A_B	cm^2	3.00E+06
	Crack-to-total area ratio	η	–	2.33E-04
Soil Stratum A	Stratum A SCS soil type			Sand
	Stratum A soil air-filled porosity	$\theta_a{}^A$	cm^3/cm^3	0.321
	Stratum A water filled porosity	$\theta_W{}^A$	cm^3/cm^3	0.054
	Stratum A soil total porosity	n^A	–	0.375
	Stratum A soil dry bulk density	$\rho_b{}^A$	g/cm^3	1.66
	Stratum A soil organic carbon fraction	$f_{OC}{}^A$	–	0.005
	User defined stratum A soil vapour permeability	k_V	cm^2	
	Stratum A effective total fluid saturation	S_{te}	cm^3/cm^3	0.003
	Stratum A soil intrinsic permeability	k_i	cm^2	1.00E-07
	Stratum A soil relative air permeability	k_{rg}	cm^2	0.998
	Stratum A soil effective vapour permeability	k_v	cm^2	9.99E-08
Soil Stratum B	Stratum B SCS soil type			Gravel Crush
	Stratum B soil air-filled porosity	$\theta_a{}^B$	cm^3/cm^3	0.390
	Stratum B water filled porosity	$\theta_W{}^B$	cm^3/cm^3	0.010
	Stratum B soil total porosity	n^B	–	0.400
	Stratum B soil dry bulk density	$\rho_b{}^B$	g/cm^3	1.60
	Stratum B soil organic carbon fraction	$f_{OC}{}^B$		0.000
Soil Stratum C	Stratum C SCS soil type			Sand
	Stratum C soil air-filled porosity	$\theta_a{}^C$	cm^3/cm^3	0.321
	Stratum C water filled porosity	$\theta_W{}^C$	cm^3/cm^3	0.054
	Stratum C soil total porosity	n^C	–	0.375
	Stratum C soil dry bulk density	$\rho_b{}^C$	g/cm^3	1.66
	Stratum C soil organic carbon fraction	$f_{OC}{}^C$		0.005
	Soil/Groundwater temperature		oC	15
	Length of contaminant source	L_c	cm	200
	Width of contaminant source	W_c	cm	1,000
	Depth of contaminant source	D_c	cm	200
	Capillary fringe - thickness	h_c	cm	0.05
	Capillary zone - thickness	L_{CZ}	cm	17.05
	Capillary zone - total porosity	n_{CZ}	cm^3/cm^3	0.375

Category	Site Characteristic	Symbol	Units	Value
Miscellaneous Intercalcs for vapour modelling	Capillary zone - air-filled porosity	$\theta_{a,cz}$	cm^3/cm^3	0.122
	Capillary zone - water-filled porosity	$\theta_{w,cz}$	cm^3/cm^3	0.253
	Vadose zone - thickness	h_v	cm	99.95
	Vadose zone - total porosity	E_t	cm^3/cm^3	0.360
	Vadose zone - air-filled porosity	Θ_{as}	cm^3/cm^3	0.241
	Vadose zone - water-filled porosity	Θ_{ws}	cm^3/cm^3	0.119
	Fraction organic carbon	f_{oc}	–	0.005
	Soil bulk density	B	g/cm^3	1.70
	Exposure duration		y	56
	Exposure duration	τ	s	1.77E+09
	Conversion factor	C	cm^3-kg/m^3-g	1,000
Trench Characteristics	Length of trench	L	cm	1,000
	Width of trench	W	cm	200
	Depth of trench	D	cm	200
	Volume of trench	V_t	cm^3	40,000,000
	Fraction of total wind speed that occurs in trench	F_t	–	0.25
	Air exchange rate in trench	A	s^{-1}	0.520
	Depth below trench to contaminated GW	z_{TRENCH}	cm	1
Atmospheric Characteristics	Mean annual wind speed	U	cm/s	416
	Ambient air mixing zone height	δ_{AIR}	cm	200
	Averaging time for flux	t	s	31,536,000

“DATENTER” sheet of the EPA J&E soil vapour intrusion model:



CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES ☐

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES ☒

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (μg/kg)	Chemical
71432	1.00E+04	Benzene

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
15	11.25	100	0	11.25	29.9	58.85	S		

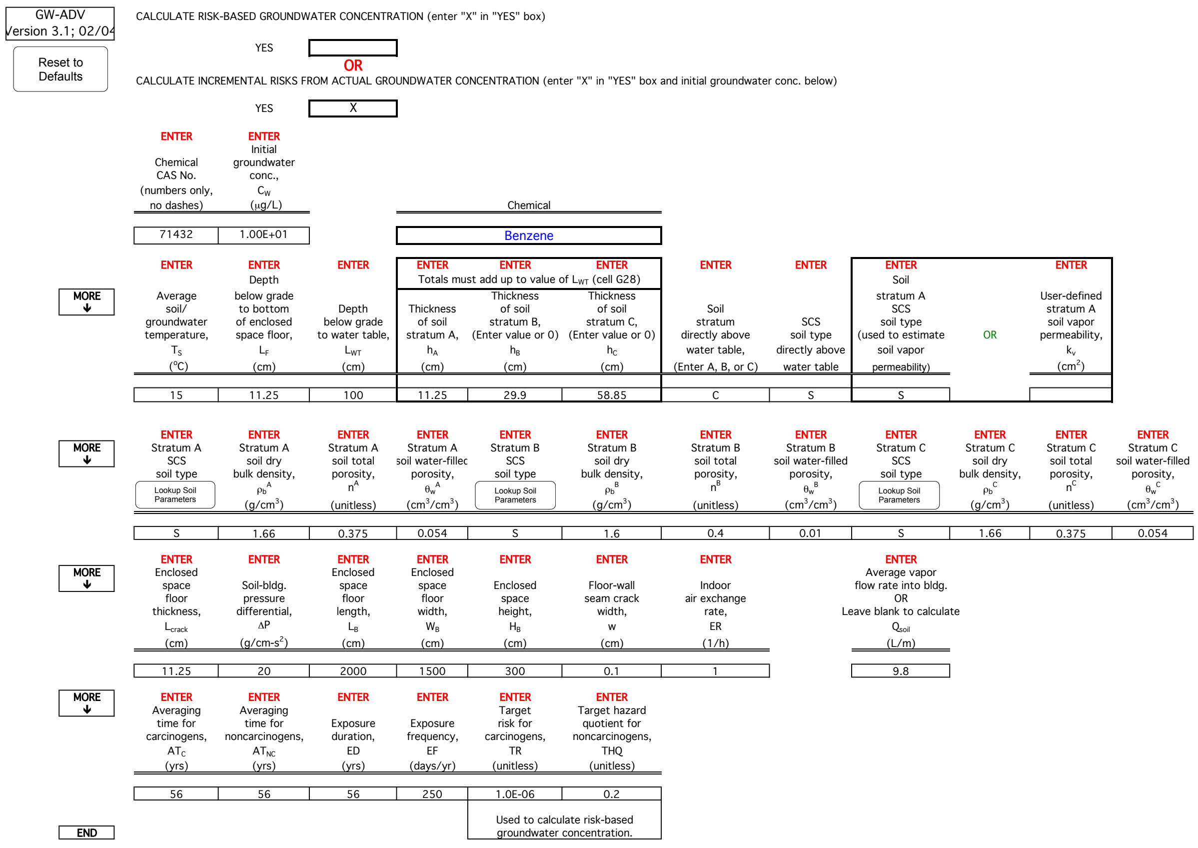
ENTER Stratum A SCS soil type	ENTER Stratum A soil dry bulk density, $\rho_b{}^A$ (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, $\theta_w{}^A$ (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, $f_{oc}{}^A$ (unitless)	ENTER Stratum B SCS soil type	ENTER Stratum B soil dry bulk density, $\rho_b{}^B$ (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, $\theta_w{}^B$ (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, $f_{oc}{}^B$ (unitless)	ENTER Stratum C SCS soil type	ENTER Stratum C soil dry bulk density, $\rho_b{}^C$ (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, $\theta_w{}^C$ (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, $f_{oc}{}^C$ (unitless)
S	1.66	0.375	0.054	0.005		1.6	0.4	0.01	0	S	1.66	0.375	0.054	0.005

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP (g/cm-s^2)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
11.25	20	2000	1500	300	0.1	1	9.8

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

"DATENTER" sheet of the EPA J&E groundwater vapour intrusion model:



GW-ADV
Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES ☐

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES X

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_W (μg/L)	Chemical
71432	1.00E+01	Benzene

MORE ↓

ENTER Average soil/ groundwater temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to water table, L_{WT} (cm)	ENTER Totals must add up to value of L_{WT} (cell G28) Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum directly above water table, (Enter A, B, or C)	ENTER SCS soil type directly above water table	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
15	11.25	100	11.25	29.9	58.85	C	S	S		

MORE ↓

ENTER Stratum A SCS soil type Lookup Soil Parameters	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-fillec porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum B SCS soil type Lookup Soil Parameters	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum C SCS soil type Lookup Soil Parameters	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
S	1.66	0.375	0.054	S	1.6	0.4	0.01	S	1.66	0.375	0.054

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP (g/cm-s^2)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
11.25	20	2000	1500	300	0.1	1	9.8

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
56	56	56	250	1.0E-06	0.2

Used to calculate risk-based groundwater concentration.

END

Appendix G3(g) of the RA provides the output from NovaTox's J&E soil vapour intrusion model. These results are typically provided on the "INTERCALCS" sheet of the EPA J&E soil vapour intrusion model. Benzene is provided below as an example from both the NovaTox and the EPA model.

NovaTox:

COC	Enthalpy of vap. at ave. soil temp. $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temp. H_{TS} (atm-m³/mol)	Henry's law constant at ave. soil temp. H'_{TS} (unitless)	Vapour viscosity at average soil temp. μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient D^{eff}_A (cm²/s)	Stratum B effective diffusion coefficient D^{eff}_B (cm²/s)	Stratum C effective diffusion coefficient D^{eff}_C (cm²/s)	Total overall effective diffusion coefficient D^{eff}_T (cm²/s)	Diff-usion path length L_d (cm)	Con-vec-tion path length L_p (cm)	Soil-water partition coefficient K_d (cm³/g)	Soil Source vapour conc. C_{source} (µg/m³)	Crack radius r_{crack} (cm)	Average vapour flow rate into building Q_{soil} (cm³/s)	Crack effective diffusion coefficient D^{crack} (cm²/s)	Area of crack A_{crack} (cm²)
Benzene in soil	8,066	3.46E-03	1.46E-01	1.77E-04	1.42E-02	2.39E-02	1.42E-02	1.65E-02	88.75	11.25	1.66E+00	8.53E+05	0.10	1.63E+02	1.42E-02	700

COC	Exponent of equivalent foundation Peclet number $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient α (unitless)	MOE Bio-Attenuation Factor α (unitless)	Infinite source bldg. conc. $C_{building}$ (µg/m³)	Finite source B term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion τ_D (sec)	Exposure duration > time for source (Y/N)	Finite source indoor attenuation coefficient $<\alpha>$ (unitless)	Mass limit building conc. $C_{building}$ (µg/m³)	Finite source bldg. conc. $C_{building}$ (µg/m³)	Final finite source bldg. conc. $C_{building}$ (µg/m³)	Soil saturation conc. C_{sat} (µg/kg)
Benzene in soil	1.37E+80	5.05E-04	1.00E+00	4.31E+02	NA	NA	NA	NA	NA	NA	NA	NA	3.07E+06

EPA:

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm³/cm³)	Stratum B soil air-filled porosity, θ_a^B (cm³/cm³)	Stratum C soil air-filled porosity, θ_a^C (cm³/cm³)	Stratum A effective total fluid saturation, S_{te} (cm³/cm³)	Stratum A soil intrinsic permeability, k_i (cm²)	Stratum A soil relative air permeability, k_{rg} (cm²)	Stratum A soil effective vapor permeability, k_v (cm²)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm³/s)
9.46E+08	88.75	0.321	0.390	0.321	0.003	1.00E-07	0.998	9.99E-08	7,000	1.00E+04	2.50E+05

Area of enclosed space below grade, A_B (cm²)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m³/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm²/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm²/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm²/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm²/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
3.00E+06	2.33E-04	11.25	8,066	3.46E-03	1.46E-01	1.77E-04	1.42E-02	2.39E-02	1.42E-02	1.65E-02	88.75	11.25

Soil-water partition coefficient, K_d (cm³/g)	Source vapor conc., C_{source} (µg/m³)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm³/s)	Crack effective diffusion coefficient, D^{crack} (cm²/s)	Area of crack, A_{crack} (cm²)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m³)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.66E+00	8.53E+05	0.10	1.63E+02	1.42E-02	7.00E+02	1.37E+80	5.05E-04	4.31E+02	NA	NA	NA	NA

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m³)	Finite source bldg. conc., $C_{building}$ (µg/m³)	Final finite source bldg. conc., $C_{building}$ (µg/m³)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m³)
NA	NA	NA	NA	7.8E-06	3.0E-02

END

Appendix G3(g) of the RA also provides the output from NovaTox's J&E groundwater vapour intrusion model. These results are typically provided on the "INTERCALCS" sheet of the EPA J&E groundwater vapour intrusion model. Benzene is provided below as an example from both the NovaTox and the EPA model.

NovaTox:

	Enthalpy of vaporization at ave. GW temperature	Henry's law constant at ave. GW temp.	Henry's law constant at ave. GW temp.	Vapour viscosity at average soil temp.	Stratum A effective diffusion coefficient	Stratum B effective diffusion coefficient	Stratum C effective diffusion coefficient	Capillary zone effective diffusion coefficient	Total overall effective diffusion coefficient	Diff-usion path length	Con-vection path length	GW Source vapour conc.	Crack radius	Average vapour flow rate into building	Crack effective diffusion coefficient	Area of crack
	ΔHv,TS	**H_{TS}**	**H'_{TS}**	**μ_{TS}**	**D^{eff}_A**	**D^{eff}_B**	**D^{eff}_C**	**D^{eff}_{cz}**	**D^{eff}_T**	**L_d**	**L_p**	**C_{source}**	**r_{crack}**	**Q_{soil}**	**D^{crack}**	**A_{crack}**
COC	**(cal/mol)**	**(atm-m³/mol)**	**(unitless)**	**(g/cm-s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm)**	**(cm)**	**(µg/m³)**	**(cm)**	**(cm³/s)**	**(cm²/s)**	**(cm²)**
Benzene in GW	8,066	3.46E-03	1.46E-01	1.77E-04	1.42E-02	2.39E-02	1.42E-02	5.68E-04	2.60E-03	88.75	11.25	1.46E+03	0.10	1.63E+02	1.42E-02	7.00E+02

	Exponent of equivalent foundation Peclet number	Infinite source indoor attenuation coefficient	MOE Default Attenuation Factor	MOE Bio-Attenuation Factor	Infinite source bldg. conc.
	$\exp(Pe^f)$	**α**	**α**	**α**	**$C_{building}$**
COC	**(unitless)**	**(unitless)**	**(unitless)**	**(unitless)**	**(µg/m³)**
Benzene in GW	1.37E+80	2.28E-04		1.00E+00	3.34E-01

EPA:

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm³/cm³)	Stratum B soil air-filled porosity, θ_a^B (cm³/cm³)	Stratum C soil air-filled porosity, θ_a^C (cm³/cm³)	Stratum A effective total fluid saturation, S_{te} (cm³/cm³)	Stratum A soil intrinsic permeability, k_i (cm²)	Stratum A soil relative air permeability, k_{rg} (cm²)	Stratum A soil effective vapor permeability, k_v (cm²)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm³/cm³)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm³/cm³)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm³/cm³)	Floor-wall seam perimeter, X_{crack} (cm)
1.77E+09	88.75	0.321	0.390	0.321	0.003	1.00E-07	0.998	9.99E-08	17.05	0.375	0.122	0.253	7,000

Bldg. ventilation rate, $Q_{building}$ (cm³/s)	Area of enclosed space below grade, A_B (cm²)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater 1.00E+01 H_{TS} (atm-m³/mol)	Henry's law constant at ave. groundwater temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm²/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm²/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm²/s)	Capillary zone effective diffusion coefficient, D^{eff}_{cz} (cm²/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm²/s)	Diffusion path length, L_d (cm)
2.50E+05	3.00E+06	2.33E-04	11.25	8,066	3.46E-03	1.46E-01	1.77E-04	1.42E-02	2.39E-02	1.42E-02	5.68E-04	2.60E-03	88.75

Convection path length, L_p (cm)	Source vapor conc., C_{source} (µg/m³)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm³/s)	Crack effective diffusion coefficient, D^{crack} (cm²/s)	Area of crack, A_{crack} (cm²)	Exponent of equivalent foundation Peclet number, 1.00E+02 (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m³)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m³)
11.25	1.46E+03	0.10	1.63E+02	1.42E-02	7.00E+02	1.37E+80	2.28E-04	3.34E-01	7.8E-06	3.0E-02

END

J&E GW Model (re-created from U.S. EPA)	**Enthalpy of vaporization at ave. GW temperature**	**Henry's law constant at ave. GW temp.**	**Henry's law constant at ave. GW temp.**	**Vapour viscosity at average soil temp.**	**Stratum A effective diffusion coefficient**	**Stratum B effective diffusion coefficient**	**Stratum C effective diffusion coefficient**	**Capillary zone effective diffusion coefficient**	**Total overall effective diffusion coefficient**	**Diffusion path length**	**Convection path length**	**Crack radius**	**Average vapour flow rate into building**
	$\Delta H_{v,TS}$	**H_{TS}**	**H'_{TS}**	**μ_{TS}**	**D^{eff}_{A}**	**D^{eff}_{B}**	**D^{eff}_{C}**	**D^{eff}_{cz}**	**D^{eff}_{T}**	**L_d**	**L_p**	**r_{crack}**	**Q_{soil}**
COC	**(cal/mol)**	**(atm-m^3/mol)**	**(unitless)**	**(g/cm-s)**	**(cm^2/s)**	**(cm^2/s)**	**(cm^2/s)**	**(cm^2/s)**	**(cm^2/s)**	**(cm)**	**(cm)**	**(cm)**	**(cm^3/s)**
Dichloroethylene, 1,2-cis-	7.68E+03	2.61E-03	1.10E-01	1.77E-04	1.19E-02	2.00E-02	1.19E-02	4.79E-04	6.05E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Tetrachloroethylene	9.50E+03	1.01E-02	4.29E-01	1.77E-04	1.16E-02	1.96E-02	1.16E-02	4.62E-04	5.88E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Trichloroethylene	8.49E+03	5.99E-03	2.54E-01	1.77E-04	1.28E-02	2.15E-02	1.28E-02	5.09E-04	6.46E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Vinyl Chloride	4.94E+03	2.09E-02	8.83E-01	1.77E-04	1.71E-02	2.88E-02	1.71E-02	6.79E-04	8.64E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02

Appendix A3: HHRA Output (A3(g): Indoor Vapour Pathway)

J&E GW Model (re-created from U.S. EPA)	**Crack effective diffusion coefficient**	**Area of crack**	**Exponent of equivalent foundation Peclet number**	**GW Source vapour conc.**	**Infinite source indoor attenuation coefficient**	**MOE Default Attenuation Factor**	**MOE Bio-Attenuation Factor**	**Indoor Building Concentration Carried Forward in Exposure & Risk Calcs:**
	D^{crack}	**A_{crack}**	**$\exp(Pe^f)$**	**C_{source}**	**α**	**α**	**BAF**	**Residential Slab-on-Grade**
COC	**(cm^2/s)**	**(cm^2)**	**(unitless)**	**($\mu g/m^3$)**	**(unitless)**	**(unitless)**	**(unitless)**	**REM $C_{building}$ ($\mu g/m^3$)**
Dichloroethylene, 1,2-cis-	1.19E-02	5.00E+02	1.77E+82	1.59E+04	4.20E-04		1.00E+00	6.67E+00
Tetrachloroethylene	1.16E-02	5.00E+02	1.19E+84	2.15E+05	4.10E-04		1.00E+00	8.82E+01
Trichloroethylene	1.28E-02	5.00E+02	4.24E+76	1.70E+04	4.44E-04		1.00E+00	7.54E+00
Vinyl Chloride	1.71E-02	5.00E+02	1.29E+57	7.53E+03	5.67E-04		1.00E+00	4.26E+00

Toddler (e.g., Resident) COC	**Source Vapour Conc. (GW) (ug/m3)**	**Attenuation Factor (GW-to-indoor air)**	**Bio-Attenuation Factor (GW-to-indoor air)**	**Indoor Vapour Conc. (GW source) (ug/m3)**	**Hours/24 Hours**	**Days/365 days**	**Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)**	**Developm Exposure Conc - No pro-rating (mg/m3)**
Dichloroethylene, 1,2-cis-	1.59E+04	1.59E+04	1.00E+00	6.67E+00	1.00E+00	9.59E-01	6.39E-03	–
Tetrachloroethylene	2.15E+05	2.15E+05	1.00E+00	8.82E+01	1.00E+00	9.59E-01	8.45E-02	–
Trichloroethylene	1.70E+04	1.70E+04	1.00E+00	7.54E+00	1.00E+00	9.59E-01	7.23E-03	7.54E-03
Vinyl Chloride	7.53E+03	7.53E+03	1.00E+00	4.26E+00	1.00E+00	9.59E-01	4.09E-03	–

Full-Life Composite (e.g., Resident) COC	**Source Vapour Conc. (GW) (ug/m3)**	**Attenuation Factor (GW-to-indoor air)**	**Bio-Attenuation Factor (GW-to-indoor air)**	**Indoor Vapour Conc. (GW source) (ug/m3)**	**Hours/24 Hours**	**Days/365 days**	**Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)**	**Developm Exposure Conc - No pro-rating (mg/m3)**
Dichloroethylene, 1,2-cis-	1.59E+04	1.59E+04	1.00E+00	6.67E+00	9.38E-01	9.59E-01	6.00E-03	–
Tetrachloroethylene	2.15E+05	2.15E+05	1.00E+00	8.82E+01	9.38E-01	9.59E-01	7.93E-02	–
Trichloroethylene	1.70E+04	1.70E+04	1.00E+00	7.54E+00	9.38E-01	9.59E-01	6.78E-03	–
Vinyl Chloride	7.53E+03	7.53E+03	1.00E+00	4.26E+00	9.38E-01	9.59E-01	3.83E-03	–

Appendix A3: HHRA Output (A3(h): Hazard Quotients for Groundwater COCs)

Toddler (e.g., Resident) COC		**Threshold Inhalation TRV (mg/m3)**				**Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)**				**Developm Vapour Exposure Conc (mg/m3)**		**GW Inhal. HQ**		**Devel. GW Inhal. HQ**
Dichloroethylene, 1,2-cis-		1.50E-01				6.39E-03				–		4.26E-02		–
Tetrachloroethylene		4.00E-02				8.45E-02				–		***2.11E+00***		–
Trichloroethylene		2.00E-03				7.23E-03				7.54E-03		***3.61E+00***		***3.77E+00***
Vinyl Chloride		1.00E-01				4.09E-03				–		4.09E-02		–

Notes:
- Bold and yellow-highlighting indicates exceedance of allowable HQ of 0.2 (0.5 for PHCs).

Appendix A3: HHRA Output (A3(i): Incremental Lifetime Cancer Risk for Groundwater COCs)

Full-Life Composite (e.g., Resident) **COC**		**Non-Threshold Inhalation TRV (mg/m3)-1**	**Years Exposed / Amortization Period**					**Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)**	**Pro-Rated AMORTIZED Vapour Exposure Conc (GW source) (mg/m3)**		**GW Inhal. ILCR**
Dichloroethylene, 1,2-cis-		0.00E+00	–					6.00E-03	6.00E-03		0.00E+00
Tetrachloroethylene		2.60E-04	–					7.93E-02	7.93E-02		***2.06E-05***
Trichloroethylene		4.10E-03	–					6.78E-03	6.78E-03		***2.78E-05***
Vinyl Chloride		8.80E-03	–					3.83E-03	3.83E-03		***3.37E-05***

Notes:
- Bold and yellow-highlighting indicates exceedance of allowable ILCR of $1x10^{-6}$.

Appendix A3: HHRA Output (A3(m): Human Health Effects-Based Values for Groundwater)

Risk Reduction & Effects-Based Values	**Indoor Inhalation of GW COCs**				
COC	**Risk Red. Req'd based on HQ for Resident**	**Risk Red. Req'd based on DEV HQ for Resident**	**Risk Red. Req'd based on ILCR for Resident**	**Risk Red. Req'd (Max)**	**EFFECTS-BASED VALUE for INDOOR VAPOUR INHALATION**
Dichloroethylene, 1,2-cis-	–	–	–	–	–
Tetrachloroethylene	11	–	21	21	24.3
Trichloroethylene	18	19	28	28	2.41
Vinyl Chloride	–	–	34	34	0.253

Appendix A1: HHRA Input (A1(b): Groundwater COC Concentrations and Component Values)

			Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine
			Const. Worker	Res.		Res.	
			Incidental	Indoor Air	Direct	Indoor Air	
		Ontario	"Contact"	Inhalation	Odour	Odour	1/2-solubility
Groundwater COC	**Geomean (µg/L)**	**Generic SCS (Table 7)**	**GW1 x 15**	**GW2**	**GW1-Odour**	**GW2-Odour**	**limit**
Dichloroethylene, 1,2-cis-	15.7	1.6	300	*1.6*	–	–	1,800,000
Tetrachloroethylene	24.6	0.5	300	*1.6*	4.4E+02	1.1E+06	100,000
Trichloroethylene	8.15	0.5	75	*1.6*	1.1E+03	2.4E+06	640,000
Vinyl Chloride (See table (iii) on the Appendix G1(b) sheet for calculation of nominal maximum)	0.841	0.5	30	*0.16*	5.3E+03	7.6E+06	4,400,000

Notes:

- Reasonable estimate of the maximum (REM) used for exposure and risk calculations and is the indicated maximum plus 20%.
- Ontario MECP Generic SCS are Table 7, for coarse soils.
- Other values are human health component values that factored into the derivation of the SCS (obtained from the MOE 2011 Rationale Document). If the component value is highlighted yellow, then it indicates the component value is exceeded by the REM.

- Component values not available for a construction worker contacting groundwater (e.g., while working in a trench or excavation). A reasonable estimate is that a worker would incidentally ingest 0.15 L of groundwater per day. This is approximately 1/15th the rate of potable water ingestion by an adult (2.3 L /day). Therefore the GW1 value was adjusted upwards by a factor of 15 for screening purposes for a construction worker.
- If a COC was identified as only requiring assessment via one pathway (e.g., contact or inhalation) it was nonetheless conservatively also assessed via the other pathway if possible (i.e., it was assessed via both contact and inhalation). This was for comprehensiveness and ease of RA preparation and review (i.e., the same groundwater COC list is maintained throughout each table of the exposure assessment and risk characterization sections). In this regard, all COCs identified as requiring quantitative assessment were conservatively assessed via pathways for which no component values are available (e.g., construction worker exposure to vapours while in a trench or excavation; exposure to groundwater vapours in outdoor air).

Site Characteristics				
Category	**Site Characteristic**	**Symbol**	**Units**	**Value**
Water Potability	Potability of groundwater		–	Non-Potable
J&E Building Inputs	Type of Building		–	Residential Slab-on-Grade
	Length		cm	1,500
	Width		cm	1,000
	Height (of mixing zone)		cm	366
	Slab Thickness	Lcrack	cm	8
	Depth below grade to bottom of floor	L_F	cm	8
	Crack depth below grade	X_{crack} or Z_{crack}	cm	8
	Crack Width	w	cm	0.1
	Pressure Differential, Building - Soil	Δp	g/cm-sec2	40
	Air Exchange Rate	ER	1/hour	0.3
	Flow rate of soil vapour into building (or leave blank)	Q_{SOIL}	L/min	8.45
	Floor-wall seam perimeter	X_{crack}	cm	5,000
	Building ventilation rate	$Q_{building}$	cm^3/s	4.58E+04
	Area of enclosed space below grade	A_B	cm^2	1.50E+06
	Crack-to-total area ratio	η	–	3.33E-04
J&E GW Inputs	Depth below grade to contaminated GW	zgw or L_{WT}	cm	416.00
	Depth to contaminated GW used in indoor model	zgw or L_{WT}	cm	416.00
	GW Source-bldg. separation	L_T	cm	408.00
	Soil Stratum A - Thickness	h_A	cm	8
	Soil Stratum B - Thickness (GW model)	h_B	cm	29.90
	Soil Stratum C - Thickness (GW model)	h_C	cm	378.10
	Soil stratum directly above water table	–	–	C
	SCS soil type directly above water table	–	–	Sand
	Capillary zone thickness	L_{CZ}	cm	17.045
	Capillary zone total porosity	n_{CZ}	cm^3/cm^3	0.375
	Capillary zone water-filled porosity	$\theta_{w,cz}$	cm^3/cm^3	0.253
	Capillary zone air-filled porosity	$\theta_{a,cz}$	cm^3/cm^3	0.122

Lookup Table (i)				
Building Characteristics	**Residential Building-with-Basement**	**Residential Slab-on-Grade**	**Commercial Building-with-Basement**	**Commercial Slab-on-Grade**
Depth below grade to bottom of floor (a)	158	8	161.25	11.25
Length (a)	1,225	1,500	2,000	2,000
Width (a)	1,225	1,000	1,500	1,500
Height (a)	366	366	300	300
Slab Thickness (a)	8	8	11.25	11.25
Crack Width (a)	0.1	0.1	0.1	0.1
Pressure Differential, Building - Soil (a)	40	40	20	20
Air Exchange Rate (a)	0.3	0.3	1	1
Crack depth below grade (a)	158	8	161.25	11.25
Flow rate of soil vapour into building (a)	8.45	8.45	9.80	9.80
Floor-wall seam perimeter (b)	4,900	5,000	7,000	7,000
Building ventilation rate (b)	4.58E+04	4.58E+04	2.50E+05	2.50E+05
Area of enclosed space below grade (b)	2.27E+06	1.50E+06	4.13E+06	3.00E+06
Crack-to-total area ratio (b)	2.15E-04	3.33E-04	1.70E-04	2.33E-04

Notes:
- Residential building-with-basement and commercial slab-on-grade buildings are MECP default building types.
- Commercial building-with-basement assumed to be same dimensions and characteristics as commercial slab-on-grade building, but with a basement that extends to 150 cm (i.e., same as residential building-with-basement), and a default commercial slab thickness of 11.25 cm, for a total depth to bottom of floor of 161.25 cm.
- Residential slab-on-grade building assumed to be same dimensions and characteristics as residential building-with-basement, but no basement means that the total depth below grade to bottom of floor is 8 cm.

(a) MECP default values.
(b) Calculated per J&E model equation.

J&E Soil Stratum A Parameters	Stratum A SCS soil type			Sand
	Stratum A soil total porosity	n^A	–	0.375
	Stratum A water filled porosity	θ_W^A	cm^3/cm^3	0.054
	Stratum A soil air-filled porosity	θ_a^A	cm^3/cm^3	0.321
	Stratum A soil dry bulk density	ρ_b^A	g/cm^3	1.66
	Stratum A soil organic carbon fraction	f_{OC}^A	–	0.005
	User defined stratum A soil vapour permeability	k_V	cm^2	
	Stratum A effective total fluid saturation	S_{te}	cm^3/cm^3	0.003
	Stratum A soil intrinsic permeability	k_i	cm^2	1.00E-07
	Stratum A soil relative air permeability	k_{rg}	cm^2	0.998
	Stratum A soil effective vapour permeability	k_v	cm^2	9.99E-08
J&E Soil Stratum B Parameters	Stratum B SCS soil type			Gravel Crush
	Stratum B soil total porosity	n^B	–	0.400
	Stratum B water filled porosity	θ_W^B	cm^3/cm^3	0.010
	Stratum B soil air-filled porosity	θ_a^B	cm^3/cm^3	0.390
	Stratum B soil dry bulk density	ρ_b^B	g/cm^3	1.60
	Stratum B soil organic carbon fraction	f_{OC}^B	–	0.000
J&E Soil Stratum C Parameters	Stratum C SCS soil type			Sand
	Stratum C soil total porosity	n^C	–	0.375
	Stratum C water filled porosity	θ_W^C	cm^3/cm^3	0.054
	Stratum C soil air-filled porosity	θ_a^C	cm^3/cm^3	0.321
	Stratum C soil dry bulk density	ρ_b^C	g/cm^3	1.66
	Stratum C soil organic carbon fraction	f_{OC}^C		0.005
J&E Miscellaneous Parameters	Soil/Groundwater temperature		°C	15
	Exposure duration		y	56
	Exposure duration	τ	s	1.77E+09
	Conversion factor	C	cm^3-kg/m^3-g	1,000

Lookup Table (ii)

Soil Properties

SCS Soil Type	K_s (cm/h)	α_1 (1/cm)	N (unitless)	M (unitless)	n (cm^3/cm^3)	θ_r (cm^3/cm^3)	Mean Grain Diameter (cm)	Bulk density (g/cm^3)	θ_w (cm^3/cm^3)	f_{OC}	SCS Soil Name	Texture
C	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092	1.43	0.215	0.005	Clay	fine
CL	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016	1.48	0.168	0.005	Clay Loam	fine
L	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020	1.59	0.148	0.005	Loam	medium
LS	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040	1.62	0.076	0.005	Loamy Sand	coarse
Gravel Crush	36,000		5.000	0.8000	0.400	0.010	1.000	1.60	0.010	0.000	Gravel Crush	
Sand	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044	1.66	0.054	0.005	Sand	coarse
SC	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025	1.63	0.197	0.005	Sandy Clay	medium
SCL	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029	1.63	0.146	0.005	Sandy Clay Loam	medium
SI	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046	1.35	0.167	0.005	Silt	medium
SIC	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039	1.38	0.216	0.005	Silty Clay	fine
SICL	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056	1.37	0.198	0.005	Silty Clay Loam	fine
SIL	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011	1.49	0.180	0.005	Silt Loam	medium
SL	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030	1.62	0.103	0.005	Sandy Loam	coarse

Notes:
- Ks = hydraulic conductivity (does not actually factor into model calculations)
- α1 = van Genuchten point of inflection in the water retention curve (does not actually factor into model calculations)
- N = van Genuchten curve shape parameter (essentially the ability of soil to retain water; higher value = less retention)
- M = van Genuchten parameter = 1 - (1/N)
- n = total porosity
- θr = residual water content (factors into the calculation of θw)
- θw = water-filled porosity
- fOC = fraction organic carbon
- Values for the 12 SCS soil types obtained from J&E model
- Values for gravel crush obtained from MECP guidance memorandum: Ks, n, θw, bulk density
- Value for gravel crush assumed by NovaTox: N (higher value than soil = less retention of water than soil)
- Value for gravel crush assumed by NovaTox: mean grain diameter (assumed 1 cm diameter of typical piece of gravel)
- Value for gravel crush assumed by NovaTox: fOC

J&E GW Model (re-created from U.S. EPA)	Enthalpy of vaporization at ave. GW temperature	Henry’s law constant at ave. GW temp.	Henry’s law constant at ave. GW temp.	Vapour viscosity at average soil temp.	Stratum A effective diffusion coefficient	Stratum B effective diffusion coefficient	Stratum C effective diffusion coefficient	Capillary zone effective diffusion coefficient	Total overall effective diffusion coefficient	Diffusion path length	Convection path length	Crack radius	Average vapour flow rate into building
	$\Delta H_{v,TS}$	H_{TS}	H'_{TS}	μ_{TS}	D^{eff}_{A}	D^{eff}_{B}	D^{eff}_{C}	D^{eff}_{cz}	D^{eff}_{T}	L_d	L_p	r_{crack}	Q_{soil}
COC	(cal/mol)	(atm-m^3/mol)	(unitless)	(g/cm-s)	(cm^2/s)	(cm^2/s)	(cm^2/s)	(cm^2/s)	(cm^2/s)	(cm)	(cm)	(cm)	(cm^3/s)
Dichloroethylene, 1,2-cis-	7.68E+03	2.61E-03	1.10E-01	1.77E-04	1.19E-02	2.00E-02	1.19E-02	4.79E-04	6.05E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Tetrachloroethylene	9.50E+03	1.01E-02	4.29E-01	1.77E-04	1.16E-02	1.96E-02	1.16E-02	4.62E-04	5.88E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Trichloroethylene	8.49E+03	5.99E-03	2.54E-01	1.77E-04	1.28E-02	2.15E-02	1.28E-02	5.09E-04	6.46E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Vinyl Chloride	4.94E+03	2.09E-02	8.83E-01	1.77E-04	1.71E-02	2.88E-02	1.71E-02	6.79E-04	8.64E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02

Appendix A4: HHRA Output (A4(g): Indoor Vapour Pathway)

J&E GW Model (re-created from U.S. EPA)	**Crack effective diffusion coefficient**	**Area of crack**	**Exponent of equivalent foundation Peclet number**	**GW Source vapour conc.**	**Infinite source indoor attenuation coefficient**	**MOE Default Attenuation Factor**	**MOE Bio-Attenuation Factor**	**Indoor Building Concentration Carried Forward in Exposure & Risk Calcs:**
	D_{crack}	A_{crack}	$\exp(Pe^{f})$	C_{source}	α	α	**BAF**	**Residential Slab-on-Grade**
COC	**(cm^2/s)**	**(cm^2)**	**(unitless)**	**($\mu g/m^3$)**	**(unitless)**	**(unitless)**	**(unitless)**	**REM $C_{building}$ ($\mu g/m^3$)**
Dichloroethylene, 1,2-cis-	1.19E-02	5.00E+02	1.77E+82	1.74E+03	4.20E-04		1.00E+00	7.29E-01
Tetrachloroethylene	1.16E-02	5.00E+02	1.19E+84	1.06E+04	4.10E-04		1.00E+00	4.33E+00
Trichloroethylene	1.28E-02	5.00E+02	4.24E+76	2.07E+03	4.44E-04		1.00E+00	9.18E-01
Vinyl Chloride	1.71E-02	5.00E+02	1.29E+57	7.43E+02	5.67E-04		1.00E+00	4.21E-01

Toddler (e.g., Resident) COC	**Source Vapour Conc. (GW) (ug/m3)**	**Attenuation Factor (GW-to-indoor air)**	**Bio-Attenuation Factor (GW-to-indoor air)**	**Indoor Vapour Conc. (GW source) (ug/m3)**	**Hours/24 Hours**	**Days/365 days**	**Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)**	**Developm Exposure Conc - No pro-rating (mg/m3)**
Dichloroethylene, 1,2-cis-	1.74E+03	1.74E+03	1.00E+00	7.29E-01	1.00E+00	9.59E-01	6.99E-04	–
Tetrachloroethylene	1.06E+04	1.06E+04	1.00E+00	4.33E+00	1.00E+00	9.59E-01	4.15E-03	–
Trichloroethylene	2.07E+03	2.07E+03	1.00E+00	9.18E-01	1.00E+00	9.59E-01	8.80E-04	9.18E-04
Vinyl Chloride	7.43E+02	7.43E+02	1.00E+00	4.21E-01	1.00E+00	9.59E-01	4.04E-04	–

Full-Life Composite (e.g., Resident) COC	**Source Vapour Conc. (GW) (ug/m3)**	**Attenuation Factor (GW-to-indoor air)**	**Bio-Attenuation Factor (GW-to-indoor air)**	**Indoor Vapour Conc. (GW source) (ug/m3)**	**Hours/24 Hours**	**Days/365 days**	**Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)**	**Developm Exposure Conc - No pro-rating (mg/m3)**
Dichloroethylene, 1,2-cis-	1.74E+03	1.74E+03	1.00E+00	7.29E-01	9.38E-01	9.59E-01	6.56E-04	–
Tetrachloroethylene	1.06E+04	1.06E+04	1.00E+00	4.33E+00	9.38E-01	9.59E-01	3.89E-03	–
Trichloroethylene	2.07E+03	2.07E+03	1.00E+00	9.18E-01	9.38E-01	9.59E-01	8.25E-04	–
Vinyl Chloride	7.43E+02	7.43E+02	1.00E+00	4.21E-01	9.38E-01	9.59E-01	3.79E-04	–

Appendix A4: HHRA Output (A4(h): Hazard Quotients for Groundwater COCs)

Toddler (e.g., Resident) COC		Threshold Inhalation TRV (mg/m3)				Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)				Developm Vapour Exposure Conc (mg/m3)		GW Inhal. HQ		Devel. GW Inhal. HQ
Dichloroethylene, 1,2-cis-		1.50E-01				6.99E-04				–		4.66E-03		–
Tetrachloroethylene		4.00E-02				4.15E-03				–		1.04E-01		–
Trichloroethylene		2.00E-03				8.80E-04				9.18E-04		***4.40E-01***		***4.59E-01***
Vinyl Chloride		1.00E-01				4.04E-04				–		4.04E-03		–

Notes:
- Bold and yellow-highlighting indicates exceedance of allowable HQ of 0.2 (0.5 for PHCs).

Appendix A4: HHRA Output (A4(i): Incremental Lifetime Cancer Risk for Groundwater COCs)

Full-Life Composite (e.g., Resident) **COC**		**Non-Threshold Inhalation TRV (mg/m3)-1**	**Years Exposed / Amortization Period**					**Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)**	**Pro-Rated AMORTIZED Vapour Exposure Conc (GW source) (mg/m3)**		**GW Inhal. ILCR**
Dichloroethylene, 1,2-cis-		0.00E+00	–					6.56E-04	6.56E-04		0.00E+00
Tetrachloroethylene		2.60E-04	–					3.89E-03	3.89E-03		***1.01E-06***
Trichloroethylene		4.10E-03	–					8.25E-04	8.25E-04		***3.38E-06***
Vinyl Chloride		8.80E-03	–					3.79E-04	3.79E-04		***3.33E-06***

Notes:
- Bold and yellow-highlighting indicates exceedance of allowable ILCR of 1x10^{-6}.

Appendix A4: HHRA Output (A4(m): Human Health Effects-Based Values for Groundwater)

Risk Reduction & Effects-Based Values	Indoor Inhalation of GW COCs				
COC	Risk Red. Req'd based on HQ for Resident	Risk Red. Req'd based on DEV HQ for Resident	Risk Red. Req'd based on ILCR for Resident	Risk Red. Req'd (Max)	EFFECTS-BASED VALUE for INDOOR VAPOUR INHALATION
Dichloroethylene, 1,2-cis-	–	–	–	–	–
Tetrachloroethylene	–	–	1.0	1.0	24.3
Trichloroethylene	2.2	2.3	3.4	3.4	2.41
Vinyl Chloride	–	–	3.3	3.3	0.253

Appendix A1: HHRA Input (A1(b): Groundwater COC Concentrations and Component Values)

			Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine	Coarse	Coarse/ Med/Fine
			Const. Worker	Res.		Res.	
		Ontario	Incidental	Indoor Air	Direct	Indoor Air	
	Geomean	Generic SCS	“Contact”	Inhalation	Odour	Odour	1/2-solubility
Groundwater COC	**(µg/L)**	**(Table 7)**	**GW1 x 15**	**GW2**	**GW1-Odour**	**GW2-Odour**	**limit**
Dichloroethylene, 1,2-cis-	26.7	1.6	300	*1.6*	–	–	1,800,000
Tetrachloroethylene	80.9	0.5	300	*1.6*	4.4E+02	1.1E+06	100,000
Trichloroethylene	12.3	0.5	75	*1.6*	1.1E+03	2.4E+06	640,000
Vinyl Chloride (See table (iii) on the Appendix G1(b) sheet for calculation of nominal maximum)	0.841	0.5	30	*0.16*	5.3E+03	7.6E+06	4,400,000

Notes:

- Reasonable estimate of the maximum (REM) used for exposure and risk calculations and is the indicated maximum plus 20%.
- Ontario MECP Generic SCS are Table 7, for coarse soils.
- Other values are human health component values that factored into the derivation of the SCS (obtained from the MOE 2011 Rationale Document). If the component value is highlighted yellow, then it indicates the component value is exceeded by the REM.

- Component values not available for a construction worker contacting groundwater (e.g., while working in a trench or excavation). A reasonable estimate is that a worker would incidentally ingest 0.15 L of groundwater per day. This is approximately 1/15th the rate of potable water ingestion by an adult (2.3 L /day). Therefore the GW1 value was adjusted upwards by a factor of 15 for screening purposes for a construction worker.
- If a COC was identified as only requiring assessment via one pathway (e.g., contact or inhalation) it was nonetheless conservatively also assessed via the other pathway if possible (i.e., it was assessed via both contact and inhalation). This was for comprehensiveness and ease of RA preparation and review (i.e., the same groundwater COC list is maintained throughout each table of the exposure assessment and risk characterization sections). In this regard, all COCs identified as requiring quantitative assessment were conservatively assessed via pathways for which no component values are available (e.g., construction worker exposure to vapours while in a trench or excavation; exposure to groundwater vapours in outdoor air).

Appendix A1: HHRA Input (A1(c): Site Characteristics)

Site Characteristics				
Category	**Site Characteristic**	**Symbol**	**Units**	**Value**
Water Potability	Potability of groundwater		–	Non-Potable
J&E Building Inputs	Type of Building		–	Residential Slab-on-Grade
	Length		cm	2,100
	Width		cm	900
	Height (of mixing zone)		cm	366
	Slab Thickness	Lcrack	cm	8
	Depth below grade to bottom of floor	L_F	cm	8
	Crack depth below grade	X_{crack} or Z_{crack}	cm	8
	Crack Width	w	cm	0.1
	Pressure Differential, Building - Soil	Δp	g/cm-sec2	40
	Air Exchange Rate	ER	1/hour	0.3
	Flow rate of soil vapour into building (or leave blank)	Q_{SOIL}	L/min	8.45
	Floor-wall seam perimeter	X_{crack}	cm	6,000
	Building ventilation rate	$Q_{building}$	cm^3/s	5.76E+04
	Area of enclosed space below grade	A_B	cm^2	1.89E+06
	Crack-to-total area ratio	η	–	3.17E-04
J&E GW Inputs	Depth below grade to contaminated GW	zgw or L_{WT}	cm	416.00
	Depth to contaminated GW used in indoor model	zgw or L_{WT}	cm	416.00
	GW Source-bldg. separation	L_T	cm	408.00
	Soil Stratum A - Thickness	h_A	cm	8
	Soil Stratum B - Thickness (GW model)	h_B	cm	29.90
	Soil Stratum C - Thickness (GW model)	h_C	cm	378.10
	Soil stratum directly above water table	–	–	C
	SCS soil type directly above water table	–	–	Sand
	Capillary zone thickness	L_{CZ}	cm	17.045
	Capillary zone total porosity	n_{CZ}	cm^3/cm^3	0.375
	Capillary zone water-filled porosity	$\theta_{w,cz}$	cm^3/cm^3	0.253
	Capillary zone air-filled porosity	$\theta_{a,cz}$	cm^3/cm^3	0.122

Lookup Table (i)				
Building Characteristics	**Residential Building-with-Basement**	**Residential Slab-on-Grade**	**Commercial Building-with-Basement**	**Commercial Slab-on-Grade**
Depth below grade to bottom of floor (a)	158	8	161.25	11.25
Length (a)	1,225	2,100	2,000	2,000
Width (a)	1,225	900	1,500	1,500
Height (a)	366	366	300	300
Slab Thickness (a)	8	8	11.25	11.25
Crack Width (a)	0.1	0.1	0.1	0.1
Pressure Differential, Building - Soil (a)	40	40	20	20
Air Exchange Rate (a)	0.3	0.3	1	1
Crack depth below grade (a)	158	8	161.25	11.25
Flow rate of soil vapour into building (a)	8.45	8.45	9.80	9.80
Floor-wall seam perimeter (b)	4,900	6,000	7,000	7,000
Building ventilation rate (b)	4.58E+04	5.76E+04	2.50E+05	2.50E+05
Area of enclosed space below grade (b)	2.27E+06	1.89E+06	4.13E+06	3.00E+06
Crack-to-total area ratio (b)	2.15E-04	3.17E-04	1.70E-04	2.33E-04

Notes:

- Residential building-with-basement and commercial slab-on-grade buildings are MECP default building types.
- Commercial building-with-basement assumed to be same dimensions and characteristics as commercial slab-on-grade building, but with a basement that extends to 150 cm (i.e., same as residential building-with-basement), and a default commercial slab thickness of 11.25 cm, for a total depth to bottom of floor of 161.25 cm.
- Residential slab-on-grade building assumed to be same dimensions and characteristics as residential building-with-basement, but no basement means that the total depth below grade to bottom of floor is 8 cm.

(a) MECP default values.
(b) Calculated per J&E model equation.

J&E Soil Stratum A Parameters	Stratum A SCS soil type			Sand
	Stratum A soil total porosity	n^A	–	0.375
	Stratum A water filled porosity	θ_W^A	cm^3/cm^3	0.054
	Stratum A soil air-filled porosity	θ_a^A	cm^3/cm^3	0.321
	Stratum A soil dry bulk density	ρ_b^A	g/cm^3	1.66
	Stratum A soil organic carbon fraction	f_{OC}^A	–	0.005
	User defined stratum A soil vapour permeability	k_V	cm^2	
	Stratum A effective total fluid saturation	S_{te}	cm^3/cm^3	0.003
	Stratum A soil intrinsic permeability	k_i	cm^2	1.00E-07
	Stratum A soil relative air permeability	k_{rg}	cm^2	0.998
	Stratum A soil effective vapour permeability	k_v	cm^2	9.99E-08
J&E Soil Stratum B Parameters	Stratum B SCS soil type			Gravel Crush
	Stratum B soil total porosity	n^B	–	0.400
	Stratum B water filled porosity	θ_W^B	cm^3/cm^3	0.010
	Stratum B soil air-filled porosity	θ_a^B	cm^3/cm^3	0.390
	Stratum B soil dry bulk density	ρ_b^B	g/cm^3	1.60
	Stratum B soil organic carbon fraction	f_{OC}^B	–	0.000
J&E Soil Stratum C Parameters	Stratum C SCS soil type			Sand
	Stratum C soil total porosity	n^C	–	0.375
	Stratum C water filled porosity	θ_W^C	cm^3/cm^3	0.054
	Stratum C soil air-filled porosity	θ_a^C	cm^3/cm^3	0.321
	Stratum C soil dry bulk density	ρ_b^C	g/cm^3	1.66
	Stratum C soil organic carbon fraction	f_{OC}^C		0.005
J&E Miscellaneous Parameters	Soil/Groundwater temperature		^oC	15
	Exposure duration		y	56
	Exposure duration	τ	s	1.77E+09
	Conversion factor	C	$cm^3\text{-}kg/m^3\text{-}g$	1,000

Lookup Table (ii)

Soil Properties

SCS Soil Type	K_s (cm/h)	α_1 (1/cm)	N (unitless)	M (unitless)	n (cm^3/cm^3)	θ_r (cm^3/cm^3)	Mean Grain Diameter (cm)	Bulk density (g/cm^3)	θ_w (cm^3/cm^3)	f_{OC}	SCS Soil Name	Texture
C	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092	1.43	0.215	0.005	Clay	fine
CL	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016	1.48	0.168	0.005	Clay Loam	fine
L	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020	1.59	0.148	0.005	Loam	medium
LS	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040	1.62	0.076	0.005	Loamy Sand	coarse
Gravel Crush	36,000		5.000	0.8000	0.400	0.010	1.000	1.60	0.010	0.000	Gravel Crush	
Sand	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044	1.66	0.054	0.005	Sand	coarse
SC	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025	1.63	0.197	0.005	Sandy Clay	medium
SCL	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029	1.63	0.146	0.005	Sandy Clay Loam	medium
SI	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046	1.35	0.167	0.005	Silt	medium
SIC	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039	1.38	0.216	0.005	Silty Clay	fine
SICL	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056	1.37	0.198	0.005	Silty Clay Loam	fine
SIL	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011	1.49	0.180	0.005	Silt Loam	medium
SL	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030	1.62	0.103	0.005	Sandy Loam	coarse

Notes:
- Ks = hydraulic conductivity (does not actually factor into model calculations)
- α1 = van Genuchten point of inflection in the water retention curve (does not actually factor into model calculations)
- N = van Genuchten curve shape parameter (essentially the ability of soil to retain water; higher value = less retention)
- M = van Genuchten parameter = 1 - (1/N)
- n = total porosity
- θr = residual water content (factors into the calculation of θw)
- θw = water-filled porosity
- fOC = fraction organic carbon
- Values for the 12 SCS soil types obtained from J&E model
- Values for gravel crush obtained from MECP guidance memorandum: Ks, n, θw, bulk density
- Value for gravel crush assumed by NovaTox: N (higher value than soil = less retention of water than soil)
- Value for gravel crush assumed by NovaTox: mean grain diameter (assumed 1 cm diameter of typical piece of gravel)
- Value for gravel crush assumed by NovaTox: fOC

J&E GW Model (re-created from U.S. EPA)	**Enthalpy of vaporization at ave. GW temperature**	**Henry's law constant at ave. GW temp.**	**Henry's law constant at ave. GW temp.**	**Vapour viscosity at average soil temp.**	**Stratum A effective diffusion coefficient**	**Stratum B effective diffusion coefficient**	**Stratum C effective diffusion coefficient**	**Capillary zone effective diffusion coefficient**	**Total overall effective diffusion coefficient**	**Diffusion path length**	**Convection path length**	**Crack radius**	**Average vapour flow rate into building**
	$\Delta H_{v,TS}$	**H_{TS}**	**H'_{TS}**	**μ_{TS}**	**D^{eff}_{A}**	**D^{eff}_{B}**	**D^{eff}_{C}**	**D^{eff}_{cz}**	**D^{eff}_{T}**	**L_d**	**L_p**	**r_{crack}**	**Q_{soil}**
COC	**(cal/mol)**	**(atm-m³/ mol)**	**(unitless)**	**(g/cm-s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm²/s)**	**(cm)**	**(cm)**	**(cm)**	**(cm³/s)**
Dichloroethylene, 1,2-cis-	7.68E+03	2.61E-03	1.10E-01	1.77E-04	1.19E-02	2.00E-02	1.19E-02	4.79E-04	6.05E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Tetrachloroethylene	9.50E+03	1.01E-02	4.29E-01	1.77E-04	1.16E-02	1.96E-02	1.16E-02	4.62E-04	5.88E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Trichloroethylene	8.49E+03	5.99E-03	2.54E-01	1.77E-04	1.28E-02	2.15E-02	1.28E-02	5.09E-04	6.46E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02
Vinyl Chloride	4.94E+03	2.09E-02	8.83E-01	1.77E-04	1.71E-02	2.88E-02	1.71E-02	6.79E-04	8.64E-03	4.08E+02	8.00E+00	1.00E-01	1.41E+02

J&E GW Model (re-created from U.S. EPA)	**Crack effective diffusion coefficient**	**Area of crack**	**Exponent of equivalent foundation Peclet number**	**GW Source vapour conc.**	**Infinite source indoor attenuation coefficient**	**MOE Default Attenuation Factor**	**MOE Bio-Attenuation Factor**	**Indoor Building Concentration Carried Forward in Exposure & Risk Calcs:**
	D^{crack}	**A_{crack}**	**$exp(Pe^f)$**	**C_{source}**	**α**	**α**	**BAF**	**Residential Slab-on-Grade**
COC	**(cm^2/s)**	**(cm^2)**	**(unitless)**	**$(\mu g/m^3)$**	**(unitless)**	**(unitless)**	**(unitless)**	**REM $C_{building}$ $(\mu g/m^3)$**
Dichloroethylene, 1,2-cis-	1.19E-02	6.00E+02	3.47E+68	2.95E+03	4.05E-04		1.00E+00	1.20E+00
Tetrachloroethylene	1.16E-02	6.00E+02	1.16E+70	3.47E+04	3.96E-04		1.00E+00	1.37E+01
Trichloroethylene	1.28E-02	6.00E+02	7.18E+63	3.12E+03	4.28E-04		1.00E+00	1.34E+00
Vinyl Chloride	1.71E-02	6.00E+02	3.90E+47	7.43E+02	5.41E-04		1.00E+00	4.02E-01

Toddler (e.g., Resident) COC	Source Vapour Conc. (GW) (ug/m3)	Attenuation Factor (GW-to-indoor air)	Bio-Attenuation Factor (GW-to-indoor air)	Indoor Vapour Conc. (GW source) (ug/m3)	Hours/24 Hours	Days/365 days	Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)	Developm Exposure Conc - No pro-rating (mg/m3)
Dichloroethylene, 1,2-cis-	2.95E+03	2.95E+03	1.00E+00	1.20E+00	1.00E+00	9.59E-01	1.15E-03	–
Tetrachloroethylene	3.47E+04	3.47E+04	1.00E+00	1.37E+01	1.00E+00	9.59E-01	1.32E-02	–
Trichloroethylene	3.12E+03	3.12E+03	1.00E+00	1.34E+00	1.00E+00	9.59E-01	1.28E-03	1.34E-03
Vinyl Chloride	7.43E+02	7.43E+02	1.00E+00	4.02E-01	1.00E+00	9.59E-01	3.85E-04	–

Full-Life Composite (e.g., Resident) COC	Source Vapour Conc. (GW) (ug/m3)	Attenuation Factor (GW-to-indoor air)	Bio-Attenuation Factor (GW-to-indoor air)	Indoor Vapour Conc. (GW source) (ug/m3)	Hours/24 Hours	Days/365 days	Pro-Rated Vapour Exposure Conc. (GW source) (mg/m3)	Developm Exposure Conc - No pro-rating (mg/m3)
Dichloroethylene, 1,2-cis-	2.95E+03	2.95E+03	1.00E+00	1.20E+00	9.38E-01	9.59E-01	1.08E-03	–
Tetrachloroethylene	3.47E+04	3.47E+04	1.00E+00	1.37E+01	9.38E-01	9.59E-01	1.24E-02	–
Trichloroethylene	3.12E+03	3.12E+03	1.00E+00	1.34E+00	9.38E-01	9.59E-01	1.20E-03	–
Vinyl Chloride	7.43E+02	7.43E+02	1.00E+00	4.02E-01	9.38E-01	9.59E-01	3.61E-04	–

Appendix A5: HHRA Output (A5(h): Hazard Quotients for Groundwater COCs)

Toddler (e.g., Resident) **COC**	**Threshold Inhalation TRV (mg/m3)**	**Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)**	**Developm Vapour Exposure Conc (mg/m3)**	**GW Inhal. HQ**	**Devel. GW Inhal. HQ**
Dichloroethylene, 1,2-cis-	1.50E-01	1.15E-03	–	7.65E-03	–
Tetrachloroethylene	4.00E-02	1.32E-02	–	***3.30E-01***	–
Trichloroethylene	2.00E-03	1.28E-03	1.34E-03	***6.41E-01***	***6.69E-01***
Vinyl Chloride	1.00E-01	3.85E-04	–	3.85E-03	–

Notes:

- Bold and yellow-highlighting indicates exceedance of allowable HQ of 0.2 (0.5 for PHCs).

Appendix A5: HHRA Output (A5(i): Incremental Lifetime Cancer Risk for Groundwater COCs)

Full-Life Composite (e.g., Resident) COC		Non-Threshold Inhalation TRV (mg/m3)-1	Years Exposed / Amortization Period					Pro-Rated Vapour Exposure Conc (GW source) (mg/m3)	Pro-Rated AMORTIZED Vapour Exposure Conc (GW source) (mg/m3)		GW Inhal. ILCR
Dichloroethylene, 1,2-cis-		0.00E+00	–					1.08E-03	1.08E-03		0.00E+00
Tetrachloroethylene		2.60E-04	–					1.24E-02	1.24E-02		***3.21E-06***
Trichloroethylene		4.10E-03	–					1.20E-03	1.20E-03		***4.93E-06***
Vinyl Chloride		8.80E-03	–					3.61E-04	3.61E-04		***3.18E-06***

Notes:

- Bold and yellow-highlighting indicates exceedance of allowable ILCR of 1x10^{-6}.

Risk Reduction & Effects-Based Values	**Indoor Inhalation of GW COCs**				
COC	**Risk Red. Req'd based on HQ for Resident**	**Risk Red. Req'd based on DEV HQ for Resident**	**Risk Red. Req'd based on ILCR for Resident**	**Risk Red. Req'd (Max)**	**EFFECTS-BASED VALUE for INDOOR VAPOUR INHALATION**
Dichloroethylene, 1,2-cis-	–	–	–	–	–
Tetrachloroethylene	2	–	3.2	3.2	25.2
Trichloroethylene	3.2	3.3	4.9	4.9	2.50
Vinyl Chloride	–	–	3.2	3.2	0.265